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# West Europe Report

SCIENCE AND TECHNOLOGY

(FOUO 3/79)



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FRANCE

PRESENT STATE OF SCIENTIFIC, TECHNICAL RESEARCH REVIEWED

Paris LE PROGRES SCIENTIFIQUE in French No 199-200, Mar-Jun 79 pp 3-42

[Report by Secretary of State to the Prime Minister in Charge of Research  
Pierre Aigrain: "Research Policy--Interdisciplinary Report on the State of  
French Science and Technology"]

[Text] France has a substantial scientific and technical potential playing a decisive role in its economic and social development.

To give a just evaluation of the medium- and long-range prospects provided for the various sectors of activity by the national research and development effort, it is indispensable to understand precisely its assets and its weaknesses, both domestically and on the international level.

And so it was that the government decided to provide our country with a permanent apparatus for evaluating French research: the report being submitted to you today represents a first and still-imperfect stage in the development of such an apparatus. In synthetic form, it sets forth the main conclusions resulting from the more detailed sectorial analyses undertaken by the General Delegation for Scientific and Technical Research (DGRST) and submitted for study to the Consulting Committee on Scientific and Technical Research (CCRST).

I hope that it will serve as a tool both of information and decision for all those assessing the importance of research in the economic and social ventures which our country is called upon to undertake in the coming years.

This report is a first step toward the establishment of a permanent instrument panel for French research. It sets forth, in necessarily condensed form, the main conclusions drawn from the more detailed sectorial analyses undertaken by the CCRST and the Consulting Committee on Scientific and Technical Research.

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Making an assessment of scientific and technical research involves first of all adopting a suitable subdivision of the very broad fields covered by research. We have used here categories similar to those adopted for the drafting of the Seventh Plan and the annual budget. This division involves some 15 sectors focused either on scientific realms or economic and social activities, or again on the study and exploitation of natural environments.

Drafting such a balance suggests moreover two types of questions:

What is the quality of French scientific production?

Is it suitably adapted to our national needs?

The answer to the first question can only be given after adopting an international context, for it is on this level that scientific results are disseminated and evaluated. One is thus forced to view the production of French teams in relation to those of the main countries, additionally taking into account the current state of advancement in the various disciplines throughout the world.

The presence of brilliant individuals in the sector is a prerequisite for the quality of the sector as a whole, but it is not enough. Thus while mentioning certain laboratories of international renown, it would be well to take into account the whole of the work force available in this evaluation effort.

We have sought moreover to set forth certain factors in success or failure, so that this understanding can lead to thought about the scientific policy. Some of the factors explaining the situation described are historical. Others may be linked with general problems such as training, personnel policy, structures, methods of disseminating knowledge, the international exposure of the teams, the planning of research, the concentration or scattering of facilities in space, etc.

Is research adapted to the needs of the country? This is a second axis for evaluation, with very different implications. The reference here is no longer the international scientific community, but the economic and social goals of the country as a whole, to which research makes, or should make, its contribution. Thus the evaluation must necessarily be related to correctly defined needs or goals. We will see that this is not always the case.

Research exists in time. Its role is to prepare for the future by clarifying options. The results achieved now and henceforth, therefore, would not suffice to indicate adaptation of the scientific and technical potential, which is also judged by its capacity to measure up to new goals. This is particularly true in new fields such as those dealing with space and the oceans, but equally so in seemingly more traditional sectors such as agriculture, which must face up to new developmental problem complexes.

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Finally, the adaptation of research to needs is measured not only by the ability to mobilize a high-quality scientific potential, but also the capacity to transfer these results to structures more or less suited to utilizing and evaluating them.

Thus overall there are two different complementary approaches which lead to two types of evaluation. These two aspects coexist, in differing degrees, in each sector.

For the purposes of clarity, the overall report is divided into three parts, corresponding to the main goals of research:

the major fields of knowledge;  
research and economic goals; and  
research and the goals of society.

The first part involves scientific evaluation, and the latter two an assessment with reference to needs. The majority of the sectors are discussed in both regards, insofar as they play a role in the general advance of knowledge, while at the same time involving the resulting economic and social activities.

This duality represents a profound reality in research, which is not by any means always properly understood. It is to be hoped that this report will contribute to showing to what extent it is research as a whole which is the issue, rather than only the aspects of it which are most applied or best adapted when it comes to meeting the needs of the nation.

#### The Major Fields of Knowledge

##### Mathematics

Mathematics is a science which is moving ahead actively. This discipline, which has developed greatly, is characterized today by the importance and the frequency of contacts bringing researchers in each field or various fields together. It is the mutual enrichment of their ideas and work which probably produces the greater part of the results achieved today.

It is undeniable that a country must attempt to maintain contact with advances in this field. The only way of doing so is to encourage researchers to remain in the vanguard. This requires only relatively limited investment, but on the other hand demands adequate recruiting of young researchers.

If we do not enjoy a monopoly situation in any particular branch, we do currently rank among the leaders in a number of them, while the others, moreover, are not without their brilliant personalities.

Without a doubt, France is contributing to world mathematical production to an extent far exceeding its demographic importance.

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Finally, it might be noted that the resolution of the problem of difficulties in communication between mathematicians and possible users of their knowledge seems to have been begun.

If the current situation is favorable, it is important nonetheless to contemplate its future development.

Work in the field of mathematics is a long-term effort which bears fruit only in the relatively distant future, on a time scale considered in terms of dozens of years. Good teams only develop through relatively broad initial recruiting, and it is therefore necessary to guarantee the maintenance of a sufficient flow to allow for the turnover in personnel. It is even more important that this flow be regular in order to ensure the rejuvenation of the teams.

A second point involves meeting centers. The very special nature of mathematical research work requires sufficiently frequent exchange. It would thus be useful to strengthen or establish meeting centers such, for example, as the Marseilles-Luminy International Center. Some of our European neighbors are well ahead of us in this regard.

#### Physics

This very broad sector covers a spectrum ranging from the most basic research (elementary particles) to fully applied sciences (electronics, metallurgy, energy), throughout which it is necessary to maintain continuity in order to avoid the development of a barrier to the propagation of innovations and the redeployment of personnel which is one of its most effective methods. This is also the sector which uses the most substantial equipment, on a scale which is sometimes continental, soon to become international. If there is such a thing as "light" physics, it too is tending to use heavier and more complex equipment, the utilization of which moreover is spreading to other scientific disciplines.

There are currently 10,000 individuals, including 4,500 researchers and teachers, engaged in basic physics research, with an overall budget of about 1.7 billion francs. The physical engineering sciences represent a supplementary potential of about 3,500 researchers.

By long tradition, this is a strong sector of French science, as recognized by Nobel prizes and illustrated by laboratories of international renown such as those of the Ecole Normale, the Ecole Polytechnique, and those at Orsay and Grenoble.

Its quality is based on extremely selective recruiting, the policy of laboratory affiliation with the CNRS [National Center for Scientific Research], and the allocation of jobs and credits. This selection, on the other hand, is hardly found in the universities, where the criteria for distribution, based mainly on teaching needs, leads to wide scattering and as a result, a lack of efficiency.

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In this sector as in others, the privileged status of our research is measured in terms of international comparison. Our physics research is well advanced. It must be encouraged still further, particularly on the level of publications and participation in international meetings.

For the analysis of the quality of French scientific production, we will examine four sectors which represent different structures in the field, and finally, the physical engineering sciences.

Elementary Particle Physics (2,800 Persons, 580 Million Francs)

This field has developed in spectacular fashion in the past 10 years. In Europe, it is above all the success of the ECNR [European Council for Nuclear Research] which accounts for almost all of the research in the sector. This European grouping of facilities has made it possible to surpass the USSR and to reach the front ranks, internationally, with the Americans. This is a particular strong point of French science, which plays a leading role in the success of the ECNR. Research is concentrated in a few large laboratories. Worthy of mention among the successes is the development of the Gargamelle bubble chamber, with which the name of Andre Lagarrigue is associated.

Mention should also be made, on the other hand, of the shortcomings of the work on gravitation and cosmic rays.

Nuclear Physics

Nuclear physics, with more than 2,000 persons and a budget of 400 million francs, has been given a clear priority in our country since 1945 (third-largest budget in the world, following Germany and the United States), with the internationally recognized quality of our laboratories as the result. This sector is currently undergoing revision of its guidelines and as a result its methods with the advent of machines of national dimensions (Ganil, Saturn II). This will eventually mean shutting down a number of regional machines, and thus will pose rather delicate problems of adaptation.

Thermonuclear Fusion

In the thermonuclear fusion sector (400 persons, 100 million francs), the concentration of efforts on fusion by magnetic confinement led to brilliant successes with the Tokamak in Fontenay-aux-Roses, from which the European Jet project and a supplementary French project, the Tokamak superconductor Toresupra, will take over.

On the other hand, research along the other line, inertial confinement, using laser beams, is scattered throughout Europe and in particular in France, and because of this, lagging far behind the United States and probably the USSR. The future of this research is a matter of concern and should be studied soon.

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Light Physics

Light physics (4,700 persons, 640 million francs). Atomic physics has been dominated for 20 years by 2 laboratories--Aime Cotton and the Ecole Normale Supérieure, which have expanded, in Paris and in the provinces, making of this sector one of the strong points in the French research field. Molecular physics has not developed so prestigiously in France.

The study of the reaction processes in atomic or molecular jets, with precise preparation of the initial stages and analysis of the final stages, represents a new direction which may restructure a large part of the atomic and molecular physics research in Paris, Orsay and the Aquitaine region. Astrophysics and atmospheric physics also represent new targets for certain teams.

Condensed Matter Physics

Condensed matter physics can claim major achievements: the laboratories in Grenoble and Orsay, the microprobe in Castaing, the basic work on liquid crystals, the use of the Lure, and the economic microscopes in Toulouse. This physics discipline is offered in all the universities, which is a clear advantage facilitating relations with local industrial activity, but an inconvenient aspect from the point of view of dispersed equipment. The development of the discipline has been dominated in recent years by the localized use of major equipment (nuclear reactors, Lure, high-tension microscopes) and the expansion of the discipline to ever more diverse subjects (liquid crystals, micelles, composite materials, single- or two-dimensional properties).

Background research on electronic components is of excellent quality: optical and magnetic properties of semi-conductors, metal semi-conductor transitions, single-dimension conductors. Surface and interface physics is a strong point, and its applications are widely varied: adsorption, catalysis, corrosion, electrochemistry.

Engineering Sciences

The basic knowledge acquired in physics, mainly light physics, spreads out into all the scientific sectors, and numerous applications will develop as this relation continues (electronics, components, instrumentation, energy, etc.). We will analyze the main sectors briefly:

a) Optics is a traditional field in France. It is being continued by a number of excellent industrial achievements (Angenieux, Jobin Yvon, Quantel) and ranks high internationally in high-performance optics. Serious gaps are to be seen in the development of materials, in optics with wide commercial application, and in laser applications.

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b) Data processing and automation have only recently gained the status of independent disciplines. They are closely linked with rapidly expanding industrial activity. Scientific production here is of good quality, as witnessed by the number of reports by French researchers at international congresses. French participation in the IFIP [International Federation of Information Processing] and the IFAC [International Federation of Automatic Control] has now reached a level comparable to that of countries such as Japan and the FRG. The renown of the main French government laboratories, such as the IRIA-LABORIA [Data Processing and Automation Research Institute-Data Processing and Automation Research Laboratory], the Programming Institute in Paris, the Institute of Applied Mathematics in Grenoble, the Automation and Systems Analysis Laboratory in Toulouse, the University of Toulouse, the ONERA [National Office for Aerospace Studies and Research], the LIMS [Data Processing and Mathematics Laboratory for the Engineering Sciences] in Orsay, the Automation Laboratory in Grenoble, the ENSM [Higher National School for Mechanics] in Nantes, and the University of Lille, is now established.

c) Mechanics and the science of materials offer a potential in this sector of about 2,000 researchers, distributed among the universities, higher schools and a certain number of bodies. In evaluating this scientific sector, we will examine mechanics and the science of materials separately. The former broadly dominates the whole, having more than half of the human resources.

Fluid mechanics is well developed in France, for despite its close links with mathematics, it has consistently developed as a function of engineering needs. Focused on hydraulic problems in the last century, it experienced its greatest expansion with the development in aeronautics and turbojets, and just recently the needs of nuclear engineering have taken over. The quality of scientific research in this sector is in general excellent, a good part of the potential being very suitably located on the international level. The number of government researchers is adequate and well located regionally. As to the distribution of personnel in terms of scientific subjects, some redeployment of university teams should be undertaken, making use of the influence of the CNRS.

Solid mechanics, on the other hand, is experiencing difficulty in freeing itself from its mathematical origin. Excluding a few brilliant exceptions (theoretical mechanics, and a few narrow breakthroughs in applied research), scientific production is at a barely mediocre level, with an orientation which is too often purely basic and academic. University research in solid mechanics for applied purposes is clearly inadequate in volume, accounting for only 15 to 20 percent of the human resources. The resolution of this problem demands a major revision on the level of research goals, to which end the sponsoring authorities (Ministry for Universities) should take action, altering in particular the allocations of credit and positions. The Directorate of Physical Engineering Sciences at the CNRS is entirely aware of this situation, and since 1977 has been pursuing an efficient orientation policy, combining the criteria of scientific quality and applied uses.

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We should note that the effort put forth by the DGRST with regard to stress mechanics has been crowned with success. It should be pursued along the lines of research on durability, as a complement to the actions undertaken with a view to economy in raw materials and energy.

The science of materials is a relatively recent concept directly linked with engineering needs, representing a meeting ground for various classic disciplines: solid physics and chemistry, rheology, solid mechanics. This scientific body is as yet very weak in our country, for the government research institutions (Ministry for Universities) have not yet incorporated it in their policy. The quality of research is good, sometimes even of international value, but extremely uneven from one sector to another.

The science of materials is a typical case in which the scattering of efforts by chemists, physicists and mechanics experts hinders the development of knowledge and tends to confine the latter to an academic circle cut off from the realities of the consumer sector. Despite the quality of the research, there is limited provision for its application. It seems, finally, that the stature of the research teams is not such as to bear comparison with the international competition. Thus it would be well to encourage the development of the main multi-disciplinary centers.

Chemistry and solid physics have won major successes on the theoretical level, accompanied by substantial progress in the practical realm (for example special steels, glass, boron fibers, etc.). However, these sectors are hard pressed to keep up today, doubtless because of the increasing interest of engineers in the useful properties of materials.

A better balance of the research potential between metallic and non-metallic materials, to the advantage of the latter, which have a great future, is to be desired.

#### Chemistry

Chemistry as a discipline, despite the basic nature of a great deal of work being done therein, can never be entirely separated from industry, which, as a user of chemistry employing 10 percent of the personnel in industry, is a key sector in the economy, which it supplies with products of all sorts. The interpenetration of the two is often great and should be greater still, the chemical industry already being one of the sectors most frequently dependent on research. The profound adaptation imposed on this industry by the new world economic conditions further emphasizes this dependence. Thus the discussion of chemistry, as it is undertaken in this report, in terms of its scientific production on the one hand, and in terms of its contribution to industrial production, on the other, is more a difference of viewpoint than an inherent one.

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The national research effort in the chemistry sector is shared by public university laboratories, the CNRS, the higher schools, and the AEC [Atomic Energy Commission], as well as the semi-public laboratories, technical centers, and to a very great extent, the laboratories of heavily concentrated industrial companies.

Naturally, by virtue of their purposes, the government laboratories devote themselves above all to basic research work, and the industrial laboratories to research for an applied purpose, almost exclusively.

It is true that chemical research should have a very continuous flow from the origin of a discovery in the laboratory, which may perhaps have seemed very theoretical at the outset, to the perfecting of a new type of production. A very special effort should be made to improve the collaboration between the government and the private laboratories so that, on the one hand, the former will have a better understanding of the needs of the latter and, on the other, in order to speed up transfers of basic research to applied usage.

The chemical research personnel total some 2,000 individuals in the government sector, to which must be added the teacher-researchers at the universities, and 5,000 researchers and engineers in industry.

The position is especially strong in catalysis, a basic sector which has been the focus of a great effort, with however inadequate work in the realm of catalysis by fixed enzymes, as compared to the activity in some foreign countries (for example, Japan). The research in quantum chemistry, radio-chemistry and nuclear chemistry is of excellent quality. It is very uneven in chemical kinetics, and more effort is required in the kinetics of heterogeneous reactions having a bearing upon the reactivity of solids and surface phenomena. Development of this discipline would contribute needed help to the field of materials chemistry, which is active but still empirical, lacking adequate scientific foundation. Similarly, research is inadequate in photochemistry and radiation chemistry. The excellent results achieved in organic synthesis are the product of a very limited number of breakthrough teams, while there is a substantial volume of university personnel focused on these problems, but most often with purely academic aims and mediocre results. An effort needs to be made to motivate these teams and improve their results, which should make a substantial contribution to the development of our pure chemistry industry.

Basic research is also most inadequate in thermodynamics, and above all in electrochemistry.

In the realm of engineering chemistry (analytical chemistry, processes, chemical engineering), the contribution made by government research is manifestly inadequate. Only a small number of teams, excellent moreover, are to be found in this field, but the means put to use are far from adequate and suffer by comparison with foreign effort. An improvement in this realm doubtless involves the activities of new types of teachers in the universities

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and the engineering schools, for this kind of research requires a multi-disciplinary approach to which chemistry in the French universities has had great difficulty in adapting, at least in practice.

Sizable human resources exist in the chemistry sector, but one might wish for much higher "productivity." To achieve this a number of small and widely scattered university teams would have to be grouped together, since too few of them attain a critical mass, and permanent collaboration between the government laboratories and the industrial laboratories on a large scale must be developed.

#### The Life Sciences

Research in the realm of the life sciences covers the basic sectors, the applied aspects of medicine, agronomy and oceanology, and finally, the technological repercussions: biological and medical engineering, pharmacy, agro-food and biotechnology as such. Here we will analyze the situation in basic or fundamental biology.

The life sciences have developed rapidly. There is active research in the field in our country. The scientific resources of the sector include 4,500 researchers and about 6,000 teachers engaged in part-time research. The initial consideration of basic biology is oriented toward increasing knowledge. Its applications may come in the long range, but also in the medium and short run. An example of the speedy application of certain of its discoveries is the birth and rapid development of genetic and enzyme engineering.

Six sectors in basic biology seem to provide examples for rapid analysis.

#### Cellular and Molecular Biology

In a first stage, beginning in 1960, molecular biology has made it possible to clarify the structure of the main biological macromolecules in bacteria, to interpret their functions in terms of structures and interactions, and to identify the mechanisms regulating and expressing the genetic heritage. In a second and more recent phase, the techniques and concepts have been extended to nucleated cells.

The French teams have won recognition recently for important work on molecular genetics and differentiation and the factors playing a role in reject reactions on chromatin, on the functional-repressor functions, on non-muscular contractile proteins and on cloning methods making genetic recombinations in vitro possible. Foreign teams have distinguished themselves with various discoveries: plasmids, enzyme inhibition, ribosome structure and function, and the new technique of producing monoclonal antibodies.

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Technical innovations make it possible as of the present to embark upon new paths of research: study of the structure of the genetic expression of the cells in higher organisms; study of intracellular and intercellular communications and the role of molecules in biomembranes; analysis of contractile proteins and the cytoskeleton.

Genetics engineering methods (genetic recombinations; genetic manipulations) have two main goals: analysis of the structure of genes and their regulation, in particular the determination of the sequence of the nucleotides of the gene and the "domestication" of microorganisms controlled by recombination through having them synthesize useful products. A number of bacterial strains produce animal proteins in this way. Successes to date are few: somatostatin, dehydrofolate-reductase, rat proinsulin and ovalbumin. There are some 50 researchers and 4 reliable special laboratories in France. Important applications of these techniques are expected in agronomy (fixation of nitrogen) and medicine (prenatal diagnosis of metabolic errors), for example, degranulocytosis.

#### Immunology

Immunology is the study of the mechanisms of identification and recognition situating the individual in relation to other individuals of his own species, individuals of other species and any foreign substance or tissue. This system of recognition is complemented by a system of defense against the "non-self." Its field of action ranges from molecular and cellular immunology to very important medical and veterinary applications (cancer, autoimmunity, parasitosis, renal and articular immunopathology, allergies, organ transplants, vaccines).

Basic and applied immunology overlap in the majority of the laboratories. In basic immunology, our country is no longer in the front ranks in the field of human and animal immunoetics, the molecular structure of immunoglobulins, and cell differentiation with regard to immune action. On the other hand, French teams are responsible for the understanding of the human histocompatibility system (HLA), the conceptual importance of which is hardly limited to the framework of biology, and knowledge of the thymic serum factor playing a role in the development of T cell lymphocytes.

There are very vigorous applications of immunology to medicine and agronomy in France. Transplant immunity, immunostimulation and immunosuppression, parasite immunology, the normal development of the immunity system in the foetus and the nursing infant and hereditary lacks of such a system in infants, immunopathology of the kidneys, joints, skin and nervous system are the main objects of research in our country. The policy of training and encouragement pursued by the DGRST since 1970, the quality of teaching, at the Pasteur Institute in particular, the enthusiasm of young people for this discipline, the establishment of new laboratories in Marseilles and the addition of an important research area at the Pasteur Institute in Paris will contribute to an upsurge of research in this field. Like molecular biology, research

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in immunology provides other fields in the "life sciences" with techniques and concepts, such that their development depends upon it and double priority is justified. Molecular biology and immunology are the sources of the transfer of research technology. A good example is seen in the extraordinary development of radioimmunity techniques in the study of natural and artificial molecules and their receptors, in experimental and human research and in clinical practice.

## The Biology of Intercellular Information in Complex Organisms

When ever more complex living pluricellular systems are developed, the signals between the cells and the organs undergo regulation, coordination, adaptation. These signals are communicated over short distances from cell to cell (kinins, prostaglandins, chalone) or over longer distances by the nervous or circulatory system. The neuromediators and the hormones are the chemical substances which specify the message. The discoveries in this field have made possible a new expression, in cellular and molecular terms, of a part of the physiology of regulation and organs.

Hormonology has been transformed in the last decade. The various hormonal signals: amines, steroids, peptides and proteins are known, in terms of chemical structure, and for the majority of them, total or partial synthesis has been achieved. New hormones have been discovered (calcitonin, somatostatin, somatomedin, VIP, endorphins, etc.). Their role is conceived as a signal between different cellular groups with a transmitter, sometimes differentiated in an endocrine gland--an often very specific system of plasmatic transport--and a membranous receiver or nuclear cytosol. The regulation of transmission and transport, the amplification of reception by a second messenger--cyclic nucleotide, calcium ions, the adaptation of receptors and signal intensity are under study and advancing. A large number of French teams have distinguished themselves in this field, above all in connection with thyroid hormones, sexual steroids, pancreatic and digestive hormones, neuroendocrinology, the "growth hormone--somatomedin" system, and the hormones regulating the metabolism of calcium. Basic French hormonology is of excellent quality. It has won several high-level international awards in the past two years.

Neurobiology is undergoing rejuvenation in our country, and in certain respects, it is extremely brilliant on an international level. Among the major works one might mention the discovery of the acetylcholine receptor, the isolation of mediators and neural hormones, the discoveries relating to the physiology of sleep and the vertical position. This discipline has quite rightly been given priority within the Seventh Plan. The desired grouping and coordination is being or will be effected: at the CNRS, Pasteur Institute, and the INSERM [National Institute of Health and Medical Research]. A vast regional operation was undertaken in Bordeaux thanks to the efforts of two universities, the CNRS and the INSERM and the regional government establishments. The most promising research trends have to do with mediators

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and neurohormones, synaptic connectors, advanced understanding of the nature of messages (multimicroelectrodes, sensory studies), neurogenetics and the effect of the environment on the phenomena of plasticity. The results of these new techniques, concepts and approaches in neurology and psychiatry are not yet readily perceived. But the closer relations between specialists in the human sciences and neurobiologists should allow a profitable reciprocal exchange within a few years, and provide the applied "neurosciences," psychiatry in particular, with an opportunity to develop a new style of scientific research. As a result, it can be expected that the efforts in this field for which the Seventh Plan provides will be expanded in the course of the coming years.

## Biology of Reproduction and Development

The study of the cellular cycle with its four phases, a third of a century ago, provided a simple model of cell development and division. On the other hand, the deciphering of the time scheduling of the basic reproductive-developmental cycle of living pluricellular sexed systems, expressed in cellular and molecular terms, is barely beginning. This aspect of biology observes the phenomena deriving from the formation of gametes and the fertilization of the egg, with the establishment of a living adult being capable of reproducing itself. The division of the egg before implantation, the implantation of the egg, the development of the forms, tissues and organs and their expression in terms of multiplication, differentiation, migration and death of the cells; the life of the foetus and the maturing of its enzymes and hormones, its nutrition and energy metabolism; perinatal biological adaptations; growth and pubertal maturing are the main sub-themes in these studies. This sector has considerable repercussions in the field of biomedical research: understanding spontaneous abortion, unraveling the mechanisms of malformation, avoiding premature birth and foetal malnutrition, decreasing the mortality and morbidity rates for newborn infants. This complex has been the focus of concerted action at the DGRST and a number of thematic undertakings at the INSERM and the CNRS. The cooperation among a number of teams from the universities, the INSERM, the INRA [National Institute of Agronomical Research] was established during the Sixth and Seventh Plans and still continues.

French teams have made considerable advances in this field: cellular migration and the origin of various organs, isolation and purification of molecules allowing tolerance of the foetus by the mother, the role of chromosomal aberrations in spontaneous abortions, perfecting of several techniques for the prenatal detection of malformations or metabolic errors, discovery of the activity of a special metabolism of vitamin D on the growth cartilage, the discovery of several cellular or intracellular endocrine receptors. The completion of a "study on foetal and perinatal pharmacology" in four years was a model undertaking.

## Biology of Interaction Between Living Organisms and Their Environment

Our country has a rather large number of teams working on the social behavior, population dynamics, natural or altered ecosystems. From the prokaryotes

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(microbial ecology of soils and oceans) to the eukaryotes, from the vegetable to the animal kingdom, these studies are of great interest. With regard to man, a number of teams are doing excellent research on population genetics, population dynamics, the relations between man and his physical, organic, psychosocial and cultural environment. The DGRST is encouraging interesting research, just at its inception, in the field of chemical environment, the biology of working conditions and athletic practice. Research on the biology of human life under extreme conditions and unusual environments, and the adaptability of biological rhythms to lifestyle and environmental changes (chronobiology) is to be encouraged.

#### Bioenergetics

This discipline developed following the application of thermodynamic studies to living organisms. At the present time, a number of French teams are firmly embarked on basic bioenergetic research (thermodynamics of biochemical reactions and ecosystems, research on photosynthesis) and applied bioenergetics (energy and biomass; production of methane and alcohol from plants; recovery of wastes and energy biotechnology). Active encouragement of this sector is urgently needed in the form of joint action by the DGRST and the CNRS.

It is clear that in the realm of basic biology, the personnel training policy has been of high quality. Three difficulties should be underlined: the insufficient number of researchers and technicians; the inadequate development of general research logistics (animal houses; cell and microbe banks; production of antibodies, reagents and marked molecules); insufficient adaptation of some disciplines involved in this research; limited teaching of genetics; shortcomings in polypeptide and nucleotide chemistry.

Finally, we should stress in conclusion two important sectors which are in real peril: bacteriology and nutrition.

Basic bacteriology and bacteriology as applied to medicine, agronomy and oceanography is attracting few young researchers. It is taught above all at the Pasteur Institute. It is urgently necessary to make an effort, in relation to certain foreign countries. Microbiology will serve as the basis of the biotechnological revolution, in genetic and enzyme engineering, in fermentation technology and the renovation of agricultural techniques. Important measures should be approved as of this year in this basic sector.

Research in food and nutrition is based on the activity of about 300 researchers. The priority programs which are underway are focused on three axes benefiting from the concerted effort of the DGRST: "eating habits," "interrelation between food and the digestive tract," "food quality and alimentary toxicology." Animal nutrition research is on an adequate level. On the other hand, it is clear that the problems of human nutrition should be approached in the coming years much more ambitiously and with determination to provide incentives in terms of men and means. Where the developed

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countries as well as the countries in the process of development are concerned, it is clear in the realm of human health that the threat of death from food deficiencies will increase in the former and the threat of starvation will increase in the latter. Now the existing system, in France and elsewhere, has major shortcomings which have accumulated historically. The possibility of nutritional research demands a complete knowledge of the chain: food and consumption, digestion-absorption, metabolism and cellular use. A common language must be acquired by the various specialists concerned with the different parts of this chain, and training, on a common basis first and later differentiated, must be provided for them. This is rarely done at the present time. Finally, research development cannot be effected in isolation. A series of measures should be correlated by the Ministry of Health, the Ministry for Universities, the Secretariat of State for Research and the research bodies involved: independent teaching of nutrition for medical students should be made compulsory; a separate post-doctoral course in human nutrition should be established, along with hospital-university careers (hospital departments, professors' and lecturers' posts) and a section or sub-section of the CCU [University Advisory Committee] specializing in nutrition. It is a vain hope that its former brilliance can be returned to research in nutrition without taking steps involving the training of doctors and the establishment of differentiated hospital-university careers. The example set in this field in the coordination of research, health and university activities in the field of health care for mothers and infants, which has provided an astonishing result in seven years, should persuade the most skeptical.

Contact between research and the French agro-food industry should be multiplied. There is little innovation in this industry and its recent work is poorly supported from a financial point of view. Many instances of misunderstanding or inertia hinder the transfer of knowledge in both directions between government research and the private agro-food sector.

## The Humanities

The humanities as a whole have experienced a remarkable development in the past few decades, characterized by the penetration, varying in degree according to the discipline, of quantitative methods, and an increasing awareness of their interdependence. Where the first point is concerned, the evaluation of the profits and risks of quantification which is now beginning justifies the hope that the problem of the relation between the humanities and the exact sciences will soon be properly set forth, guaranteeing a satisfactory development of these disciplines. The second direction, accompanied by a gradually more open approach to the natural sciences, and in particular biology and physiology, paves the way, for its part, toward a global understanding of man, his activities, and the conditions of his existence.

These new prospects rarely benefit from structures adequate for their development. The human sciences have few specialized bodies and scientific

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production, essentially in the universities, suffers from the main shortcomings of these institutions: limited research penetration, scattering of resources, lack of evaluation, nonexistent program coordination. The efforts made by the CNRS, and those made more recently by the research mission have indeed contributed to altering this general situation, but it is disturbing to note, as those responsible for publication in the realm of the human sciences recently did, that the outstanding individuals publishing in recent years are almost entirely outside the universities. The most notable non-specialized accomodating structure is currently the Ecole des Hautes Etudes en Sciences Sociales (School of Higher Social Science Studies), which since its establishment has been able to maintain high-quality teaching and to develop real research programs. This institution seems to meet all of the conditions needed to establish integrated training on a high level, made indispensable by the development of this research sector.

Where means are concerned, they seem to be adequate as a whole, but their distribution very often joins together the faults of feudalism and egalitarianism: maintenance of positions won, favoritism and scattering of resources cancel out the efforts made on the financial and human levels such that good teams often lack what they need while others, justified by their existence alone, are supported without control.

The scientific analysis pursued, in particular by comparison with foreign research, reveals the following:

A very satisfactory situation in history, prehistory, and, generally speaking, in anthropology. The French historical school is one of the most notable and fertile on the international scene. It includes a wide diversity of talents and approaches and benefits from an excellent structure with the Ecole des Hautes Etudes. Prehistory is the most advanced sector in French archeology. The application of rigorous scientific methods, the establishment of continuing relations with ethnology and the very high quality of the recording of observations obtained from excavations guarantee a broad effect for this specialty. Finally, French anthropology can boast of notable achievements both in the realm of physical anthropology, which interrelates with the biochemical sciences, and in social and cultural anthropology, thanks in particular to the original and rigorous research pursued at the laboratory of the College de France, under the direction of C. Levi Strauss.

There is a situation which is honorable on the whole in demography, mathematical economics and psychoanalysis. Demography benefits from an excellent accommodating structure thanks to the INED [National Institute for Demographic Studies]. The concepts of this discipline are well established, its methods are homogenous and the training satisfactory. Mathematical economics represents a strong point in French economics: both the engineering schools and public enterprises have encouraged research in this sector. As to psychoanalysis, the theoretical nature of which is closely linked with a therapeutic aspect, it offers a richness and diversity in France found in few foreign countries.

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There are a few remarkable achievements in an overall complex of average quality: sociology, economics, philosophy and linguistics. French sociology has been clearly marked for some years by an often disordered proliferation of empirical works undertaken in particular at the request of administrations, with widely varying success. However, this relative mediocrity of production as a whole has been accompanied by research of high quality carried out by several teams, most often in Paris. French economic science, which revealed an undeniable lag on the international level until recently, seems to be beginning a new upsurge thanks to the development of a demand for research for purposes of forecasting, the establishment of high-quality teams within the ministries, the public enterprises and the General Planning Commissariat, and the penetration of economic instruction in the universities and higher schools. Philosophy owes its real current impact abroad to remarkable but isolated individuals. It suffers to a considerable extent from the shortcomings of the universities, which are its main structural accommodation. As to linguistics, if the principal stages in its development are most often taken outside France, it must be recognized that the crisis in linguistics characterizing the post-Chomsky period led to original and fertile research on French territory.

A very middling situation exists in numerous sectors of the law, psychology and the archeology of historical periods. In the law, in which individual research predominates, the achievements are not consistent with the important university system available to us (with the exception of the study of substantive law, in which satisfactory work has been done). This discipline, which has had a certain influence abroad, is actually experiencing difficulties in adapting to the changes in goals and methods which have come about as a result of the development of knowledge and of modern society. French psychology suffers from a scattering of teams and dispersed efforts. It is competitive only in a very limited number of sectors. Archeology of historical periods is to a considerable extent the victim of quite unsatisfactory organization of research, lack of adaptation of training to the demands of modern archeology, and a major geographic and thematic imbalance.

A frankly critical situation exists in political science, social psychology and modern geography. In political science, the upsurge which followed World War II and the establishment of the National Foundation of Political Sciences seems to have led to an uncertainty about the nature, the goal and the methods of this discipline, which is now undergoing real difficulties in defining itself clearly in relation to the neighboring disciplines. The sector as a whole is tending currently to limit itself to electoral sociology. Social psychology is currently underdeveloped, indeed moribund, in France. It has few researchers and still fewer significant works.

As to human geography, after playing a very positive role in social science research at a time when the disciplines making up this sector were still relatively undeveloped, it seems today considerably impoverished, to the point of experiencing a veritable identity crisis, clearly seen in its

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splintering into sectors of unequal development, of scientific value which varies widely and is poorly interrelated.

Environmental Studies

Space

Space should be viewed from three viewpoints: knowledge of space, penetration of space, and use of space technology.

Where the knowledge of space is concerned, it is basically a matter of fundamental disciplines, one being traditional astronomy, and the other, more recently developed, spatial geophysics.

The position of French science in these two disciplines is quite honorable. Although French researchers have not participated in the most spectacular discoveries in recent years, they have contributed greatly to a more profound knowledge in this realm, which is currently undergoing a real expansion. They have offset the relative handicap resulting from the lack of high-performance telescopes in France by very great ingenuity in instrumentation. The delay experienced in large telescopes is in the process of being partially made up thanks to new investments. However, the very limited recruiting in recent years and the decline in operational resources are such that there is a risk that these investments cannot be put to full use.

Moreover, these disciplines still remain too separate structurally from basic physics, of which, however, they are tending more and more to represent a basic branch.

The penetration of space and the use of space technology constitute a space program as such. In this sector, France has pursued a very continuous and tenacious policy thanks to which, although sums considerably lower than what has been spent by the two major powers have been devoted to the purpose, it has achieved very good results with limited but important goals (excluding in particular the launching of men into space). This policy was drafted and implemented by the CNES [National Center for Space Studies], which has made an effort to develop the capacity and the competence of the government and industrial research laboratories to this end.

It was in this way that first of all mastery was acquired of the basic techniques giving access to space, launching and satellite technology.

With regard to launchers, this policy is reflected in the success of the Diamant (six successes out of eight launchings) and several successes on the satellite level. A policy was then undertaken in cooperation with the other European countries for two purposes:

On the one hand, to gain autonomy in the means of launching satellites for practical uses. This involves the Ariane program which should, by 1980,

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yield a launcher which is competitive technologically and economically with the classic American launchers; and

On the other hand, catching up the lag with regard to the Americans in the production of satellites for practical uses, first of all in telecommunications (Symphonie, OTS) and meteorology (Meteosat). The lag seems in fact to have been made up at least on the level of technical performance, if not in the realm of ability to compete economically. More recently, in deciding to pursue the Spot project (with launching plans for 1984), France has entered the very promising realm of the use of satellites for the management of land resources. On certain points (spatial resolution, stereoscopy) Spot will be superior in performance to its American competitors.

Finally, on the scientific level, a dozen French laboratories for basic research attached to the universities, the CNRS, the AEC and the CNET [National Center for Telecommunications Studies] have taken their place on the highest international level, as is evidenced by the rank assigned them after severe selection from among Russian, American and European satellites.

#### The Earth Sciences

These have as their purpose the study of the terrestrial globe, its history, and the phenomena for which it is the scene. They involve also and above all the study and the rational management of the natural resources essential to economic development.

From simple sciences of observation using the magnifying glass and hammer, the earth sciences have become analytical sciences using vastly more complex methods and means, and requiring closer relations with the physical, chemical and mathematical sciences. Aptitude for these changes has made a selection among the teams. Distribution in space (in the territory of France) is satisfactory, although selective reinforcement would be desirable. International cooperation in this field is a duty, for geological phenomena do not honor frontiers. French scientists have realized this and their impact abroad is strong, if indeed inadequately coordinated.

From the point of view of the knowledge of concern to us here, the status of our scientific production could be described as follows:

Few teams, in number, but of high level, for the study of the profound zones of the planet;

Very active participation on the international level (in particular the IPOD [International Phase of Ocean Drilling] program) in the veritable scientific revolution brought about by the theory of plate tectonics, wherein the existence of maritime resources, in particular in connection with the CNESO [National Center for Exploitation of the Oceans] has enabled French teams to take their place in the leading international ranks;

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A brilliant past record in the study of surface geological phenomena, but difficulty in the adaptation of some teams to the advances in research and experimentation techniques; and

A visible lag in soil cartography (pedology), in the process of being caught up in geological mapping, a priority within the Seventh Plan because of its importance to the exploitation of subsoil resources.

Oceanological Research

Oceanological research is to a very great extent exploration in a new realm, because it was unknown just a few years ago. This field is very broad, very diverse and, finally, very difficult of access except on the surface.

This research sector, relatively neglected to date, has aroused great interest since concern with the increasing shortage of resources and the need to protect our environment developed.

An ever more profound understanding of the properties of the environment and the underlying soils, without however being an indispensable prerequisite, is nonetheless becoming more and more useful, indeed necessary, when it comes to developing the exploitation of them.

Thus in the more advanced countries we are witnessing a great upsurge in oceanological research. France occupies a very honorable place in this overall effort, with some strong points (geology, geophysics, technology) and some weaker ones (physical and chemical oceanography).

Although modest, the resources invested in geology and geophysics (120 positions, 65 million francs, not including oil research) have led to the most remarkable results on the international level, in particular in geophysics. The French-American FAMOUS [French-American Mid-Ocean Undersea Study (1974)] (involving exploration of the ocean valleys) operation and the International Program of Ocean Drilling (IPOD) for the study of the continental shelves, should be mentioned. The French school of sedimentology is also very brilliant.

The availability of systems of submarine penetration, among the most advanced in the world, has been a basic factor in success. The future will depend on the modernization and development of these facilities.

The situation is not so good in physical oceanography, and above all in chemical oceanography (140 positions, 40 million francs). The basic purpose of physical oceanography is the study of the thermal and mechanical states of the oceans, on which states phenomena as important as the distribution of sedimentary deposits, biological productivity of the various zones, and the development of the earth's climate in the medium range depend. In this discipline, French researchers have made some internationally known

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contributions but, in addition to being few, their efforts have been inadequately focused. Chemical oceanography, which is absolutely essential to the study of the development of pollutants in the oceanic environment, as well as that of natural substances, is extremely underdeveloped in France in comparison to foreign efforts, particularly in the United States.

Biological oceanography, the purpose of which is the study of living beings in the sea, is a discipline with an older tradition and strongly developed in France (ranking third in the world after the United States and Great Britain), in particular at the universities, which have been provided with a number of marine stations. This university research, however, tends to remain too descriptive, relatively dispersed and insufficiently incorporated in the discipline of biology as a whole. Marine ecology is well developed. On the other hand, marine microbiology, although essential, is almost non-existent.

All of this effort toward a better understanding of the oceans has been accompanied by technological research which has found its main point of application in oil exploration and exploitation. French researchers and engineers have achieved excellent results here, earning us a strong commercial position both for the platforms and for marine drilling techniques.

#### Atmospheric Research

Atmospheric research (200 persons, 200 million francs, including 145 million francs for the space program) suffered from a considerable lag in France a few years ago, which has since been partially remedied where short-term numerical estimates are concerned. The lag continues to exist however in cloud physics and climatic research. On the other hand, excellent results have been achieved in instrumental technology and France is well situated in space meteorology. The difficulties in communication between university research on the one hand and that done within the national meteorological service, on the other, was certainly the cause of some shortcomings in the present situation. There has however in the past two years been a substantial improvement in this connection.

#### Research and Economic Goals

##### Energy

French energy research has behind it an enviable history: organized for some 30 years on the basis of several large government and semi-autonomous establishments (Charbonnages de France [French Coal Mines] and the CERCHAR [Center for Studies and Research on French Coal Mines], the IFP [French Petroleum Institute] and the oil companies financed by state capital, the AEC, the French Electric Company and the French Gas Company), it has allowed our country to develop the most modern techniques and to guarantee its energy supply under good conditions to date.

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But the balance which gradually developed among the activities to be pursued in the different fields was challenged by the crisis which became evident at the end of 1973. To the traditional goal of energy production the goal of energy saving in all forms of its use has been added. If for the classic mass energy sources there are competent teams, well integrated in large, responsible organisms for supplying the country with energy, it should also be possible to rely for the future on the university teams which have been established in the past few years and which immediately established close links with the existing industrial teams.

Several general characteristics of energy research merit emphasis:

The importance of the time lag needed for the development and then the industrial production of new energy chains: 36 years after the development of the Fermi reactor, nuclear energy accounts for only 3.5 percent of our national supply;

The heavy research investments make international cooperation necessary, the European community framework being that favored, for France; and

The increasing importance of coordination, since new programs place demands on the varied potential to be found in different organisms. The total public and industrial research-development-demonstration effort can be estimated at 6.5 billion francs.

Four major fields can be distinguished:

Fossil Fuels

These include mainly coal and hydrocarbons, with a striking contrast between them.

While our country is but a marginal producer of hydrocarbons, and consumes only three percent of the world total, French research has played a very honorable role in the developing of oil exploration and exploitation techniques, thanks in particular to the activities of the IFP [French Petroleum Institute] and the French oil companies, which have long been supported by the government authorities.

The research and development programs undertaken for the past 15 years or so in the maritime oil sector represent without a doubt a major achievement in our energy policy, and have brought us remarkable technical successes (exploratory drilling at considerable ocean depths, concrete or semi-submersible platforms, production and laying of pipe, underwater work). All of this progress is reflected in the fact that France is currently the second most important marine technology exporter, after the United States.

Research pertaining to assisted recovery is more recent and has led to major results. It is however necessary to establish a national program the basic

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goal of which would be the achievement by French industry of renown and technical credibility based on experience, parallel to our success in the maritime field.

Where natural gas is concerned, France plays an exceptional role in the field of liquefaction and transportation (construction of nearly 56 percent of the methane tankers in use).

On the contrary, the reverse is true in the coal sector, where our unfavorable position within a much more active international context may have undesirable repercussions eventually on our economy and our independence in energy sources. Moreover, all the experts agree in saying that coal will assume an important role again before the end of the century.

If the CERCHAR teams are competent in the realms of extraction technology and mine safety, it must in fact be noted that there are no longer in France any coal geologists and that research on the use or conversion of coal is insignificant. One can however hope that the programs getting underway on the improvement of combustion in fluidized beds, coal-fuel oil mixtures, nuclear gassification and underground gassification at great depths (the only foreseeable technique for exploiting our deep reserves) will allow us in time to recover the distance we have fallen behind in relation to foreign efforts (United States, Germany, Great Britain and Japan).

#### Nuclear Energy

France is one of the countries which has undertaken to master the whole of the nuclear cycle, from uranium prospecting to the reprocessing of irradiated fuels and the storage of wastes, including uranium production, its enrichment, the production of fuel elements, and the development and production of reactors. In this connection it has two main assets in the existence of a large specialized research body, the Atomic Energy Commission, and a client which is of international dimensions and technically competent--the French Electric [Power] Company. In this complex chain, there are without a doubt strong points where we are undeniably among the leaders, but there are also sectors in which we rank second to foreign effort.

Among our strong points, mention should be made first of all of enrichment by gaseous diffusion (EURODIF [European Diffusion Agency] isotopic separation plant), and, for the future, the new chemical separation process, on which the work of development began some dozen years ago. At the other end of the cycle, it should be stressed that France is still the only country with an operational plant for the reprocessing of irradiated fuels, and that it is very well situated where the processing of waste is concerned.

In the reactor field, the situation varies depending on the line.

Where light water reactors are concerned, the experience acquired by the AEC, the FRAMATOME [Franco-American Atomic Construction Company] and the

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EDF [French Electric Company] should make it possible for the national construction sector to move gradually from its position as a Westinghouse licensee to partnership status at the end of the present license period (November 1982).

The rapid neutron breeder reactors, one of the great lines of the future, represent without any doubt one of the great achievements of our nuclear policy. France plays a preponderant role in this sector, thanks to the continuity of the policy it has pursued for 20 years. Moving beyond the Rapsodie and the Phenix, the production of the Superphenix marks the real end point of the developmental phase for this line (1,200 electric megawatts).

On the other hand, our position with regard to high-temperature reactors is weaker. On the international level, for that matter, the future of this line is uncertain.

New Energy Sources and Technology

The energy crisis revealed the limited nature of the resources used today and the need to promote the use of renewable sources of energy, as well as to develop new storage, transportation and conversion techniques. Doubtless it is too soon to analyze the results of a very recent effort, but the basic point is the vigor with which the teams working in widely varied disciplines and bodies have been mobilized in the service of this national priority, thus constituting a real factor in success for the future.

A wide variety of fields is involved. Research in the low-enthalpy geothermal field has led to various double-faceted operations. The energy of the sea and wind, on which a certain number of experiments were made in the past, in particular under the sponsorship of the EDF, is now being studied in the light of new economic conditions. The same is the case for the energy use of farm byproducts and biomass, more generally. The production of hydrogen by electrolysis as a means of storing nuclear energy is the focus of major effort. On the other hand, the future of fuel cells for propelling vehicles seems very uncertain, despite the research done in the past decade.

In fact, two new sources of energy seem likely to play an important role in the long run: solar energy and controlled thermonuclear fusion.

Research on solar energy covers the whole field of possible applications, although some of them are of less interest to France than to the countries in the process of development. But the effort has been focused above all on two special fields: thermodynamic conversion on the one hand, which has led to the drafting of plans for a number of experimental plants, and photovoltaic conversion on the other, perhaps more promising in the long run, and an effort which will benefit from impetus within the framework of a "photovoltaic plan" which is now being drafted. The CNRS has without a doubt played a very important role in this research with the PIRDES [Interdisciplinary Research and Development Program for Solar Energy]. In the realm of housing,

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the rediscovery of "passive" solar energy has given rise to various experiments under the sponsorship of the Construction Plan. Nonetheless, in order to achieve economic success, our very favorable situation on the research level must be transferred to an industrial strategy, which the COMES [Solar Energy Commission] is working to define.

Where fusion is concerned, France played a preponderant role until recent years thanks to the activities of the AEC in the fields of magnetic confinement and plasma physics (Tokamak TFR 600 in Fontenay). Our determining role in the European JET program bears witness to this, but is not sufficient to retain our capacity to conceive machines for tomorrow. On the other hand, research on inertial confinement remains scattered.

Rational Energy Use

If energy savings have for a long time been one of the goals of research in certain special use sectors (in particular air and maritime transport), it must indeed be admitted that they did not become a national priority until 1974. Energy savings have been but one criterion, generally speaking, among others, in the decisions made by industry or the final users. Taken together, the activities with a view to energy savings are of a scattered nature, even though they are oriented along general guidelines, and it is difficult to make an evaluation of the research activities in progress.

It can only be noted that in the short term, the difficulties encountered are less on a technical than on a financial level, and that the sponsoring structures should make it possible to place industrial interests, evaluated in purely economic terms, on the level of collective interests. After 1985, however, the research activities undertaken should exert a spectacular influence on the residential and tertiary sectors (rational and systematic heat insulation of buildings), and on the transport sector (specific consumption decline of 15 to 30 percent), as well as industry (utilization of effluents and wastes, improved automatic heat pumps, heat-strength combinations, new crushing methods, non-thermal separation methods, etc.). Finally, the research in progress on secondary energy storage justifies optimism as to the uses of such energy in the medium time range.

Exploitation of Environmental Resources

Exploitation of Land Resources

France is heavily dependent on foreign sources for the mineral raw materials it consumes. Domestic mining production supplies our industry with only 15 percent of its needs. Recycling supplies 30 percent of consumption, on an average, and thus imports account for 55 percent of domestic consumption, although the situation varies greatly with each different substance.

This situation involves the following:

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A major annual drain of foreign exchange. In 1977, imports of mineral substances reached 18 billion francs. The deficit in the balance of payments in this category was 7.75 billion francs in that same year for ores, metals and non-ferrous semi-products as a whole, as compared to 55 billion billed for oil; and

Very substantial vulnerability with regard to our supplies.

The problem for research is to develop methods of prospecting and processing mineral substances in order:

To make full use of French resources, on the one hand; and

To market our technology abroad, generally as a counterpart to a certain guarantee of supply, on the other.

Where geology and the study of mineral deposits, surveys and the printing of maps of France on a scale of 1:50,000 are continuing. These maps today pertain increasingly to crystalline or metamorphic terrain, which is likely to contain numerous indications of ore and thus is of direct interest to the Mineral Resources Inventory of France program established in 1975 by the government. With this same end in view, the syntheses drafted on the level of French metal-bearing provinces (rich in indices of mineral ore), the distribution of deposits within these provinces and metal indicators (prospecting guides) for each type of deposit are the subject of research made desirable by the recent discoveries of a number of indications in the old massifs (like copper, lead and zinc in Brittany, or tungsten in the Massif Central).

The development of prospecting methods is also one of the key elements in discovering hidden deposits.

In geochemical prospecting (on soils or alluvia), performance analysis is used today in temperate climates. A number of methods seek the same result in tropical or glacial climates. Elsewhere, an intensification of research on the use of geochemistry in rocks and minerals is found, following initially encouraging results in certain types of massifs.

In geophysical prospecting, there are but few research teams. The effort today is focused on the development of diagraphics and geophysics based on drilling. Generally speaking, an improvement of material resources and the processing of data gathered is desirable.

Notable progress has been made in the realm of utilization of ores and useful substances. French teams have reached the front ranks internationally, both in the most basic research (solid-liquid interaction, for example) and the most applied aspects of research (development of a precise target). This subject of ore processing provides a key both to developing use of our national resources and our contributions abroad.

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Finally, a special effort is being devoted to the rational use of raw materials and recycling. Certain developments are currently underway on the utilization of industrial wastes, the recovery of metals from very poor ores and the recycling of household garbage.

Water resources merit equal attention. French hydrogeological teams play a preponderant role on the international level, reflected in a heavy export flow of knowledge and technology. However, if progress continues to be notable on water quality, a certain stagnation in the results where research on quantitative aspects is concerned can be seen, despite the credit allocations for karst or granitic areas after the 1976 drought.

Exploitation of Ocean Resources

The first oceanological research work organized was pursued under the sponsorship of the DGRST and its Joint Action Committee (COMEXO). In 1967, to reinforce this activity, the government decided to establish the CNEXO [National Center for Exploitation of the Oceans], assigning to it the task of assembling and putting to use the means necessary for the exploration of the oceans and preparation for their exploitation (oceanographic vessels, submarines, buoys, test basins, etc.) and coordinating the activity of the numerous French laboratories with this end in view.

The CNEXO has had unequal success in its tasks. It has set up and managed substantial domestic resources. Under its guidance, research programs have been launched in entirely new sectors such as aquaculture (non-traditional) and the exploration of nodule fields. But generally speaking, we are still quite far from a situation in which oceanological research as a whole would be structured in clear programs, putting all capabilities to ordered use.

Living Resources

Research with a view to the exploitation of living resources is divided into halieutics (fishing), traditional aquaculture (oyster and mussel breeding) and the new aquaculture.

In the realm of fishing research, France has lagged and finds itself ill prepared to deal with the new situation created by the over-exploitation of stocks and the extension of the zones of economic interest to 200 miles. An effort should be made to strengthen it, among other things by amending the bylaws of the ISTPM [Scientific and Technical Institute for Ocean Fishing], and reorganizing the relations among the three main bodies concerned: the CNEXO, the ISTPM, and the ORSTOM [Bureau of Overseas Scientific and Technical Research].

The research on pathology in oyster culture is inadequate. Finally, excellent results have been achieved with certain species, above all in cultivation of the intensive type, within the new aquaculture. However, a number of obstacles remain to be overcome in order for this sector to assume significant dimensions.

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Finally, it should be noted that university researchers, of whom there are moreover a number in marine biology, are playing an entirely inadequate role in the whole of the research effort oriented toward exploitation of the living resources of the sea.

Mineral Resources

The situation in the oil sector, both in terms of overall development and relations between the public and private sectors, is excellent (see II. 1). An effort must nonetheless be made to retain the advance in a sector which is developing rapidly and is highly competitive, and the technological research effort should to this end be increased still further.

With regard to polymetallic nodules, the research pursued in France has led to the discovery of apparently exploitable zones, but the means for this exploitation have not been developed. Such development, at least if it were undertaken with domestic resources alone, would involve allocating credit to it in an amount far in excess of what is currently being spent in this sector.

Thus it would be well to examine very closely the desirability of this undertaking, in view of the supply prospects, mainly for nickel, in the medium and long range, and taking into account the other options capable of satisfying the goals of our raw materials policy.

We have moreover somewhat neglected the exploitation of other potential maritime assets: metallic ores on the continental shelf (outside metropolitan France), and the Red Sea salt flats.

On the other hand, we have not fully exploited our early lead in submarine penetration and have not been able to win the civilian submarine market.

The Marine Environment

This is a sector the importance of which for the future is known to all, but one in which our resources are very scattered and inadequate for some disciplines (in particular marine chemistry). It is necessary to remedy these shortcomings, to display the will to attack the problems and to translate them into clearly defined programs. Independent of the direct justifications, such an effort is likely to have not inconsiderable economic repercussions, in the form in particular of exports of services for studies of coastal developments.

Meteorology

Meteorology is subject to heavily increasing demand from a large number of users. The reason for this situation is that the meteorological parameters are becoming substantial in many human activities oriented toward intensive exploitation of resources: energy, agriculture, major projects, maritime exploitation, tourism, transportation.

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The National Meteorological Service, which is the government body providing this service, is having ever-increasing difficulty in meeting this demand, for its resources have not by any means kept up with the advance in this demand, and on the other hand, the lag in French research is making itself particularly keenly felt. However, space and data processing technology provide an opportunity to make great progress in meteorological forecasting, providing that human resources in sufficient numbers are assigned to this research, which is far from being the case currently.

Space

The use of space technology is without a doubt likely to develop considerably in the world, on the one hand to replace classic technology (in particular in telecommunications), and on the other, to provide new services (direct television, meteorology, observation of the earth, in a few years, perhaps new materials).

In France, interest in space technology for domestic purposes has only developed very recently, and we have the promoters of French space development to thank for the extensive lead established over the needs expressed by users. It is thanks to this that the means and technology for launching are available today for the Telecomm I project (the main mission of which is data transmission) launched in 1979 by the General Telecommunications Directorate. These resources are also awaiting completion of certain developments by French Television with a view to a direct television satellite, as well as for a certain number of military uses. With the Telecomm I project, France should become a pioneer in Europe in specialized telecommunications, while, with broad French participation, the Europeans may be the first to establish an operational system for direct television.

In the realm of observation of the earth by means of multi-spectral images, it is possible that the same phenomenon will be reproduced. The Spot project established in 1979 and scheduled for completion in 1984 does not for the time being meet the demand clearly expressed in economic terms, but there is every indication that the use of this technology for the management of resources (agricultural, hydrological, etc.) will be widespread a dozen years from now, and preparations must be made for this.

But the uses of space technology will be still more spectacular in the new countries where, lacking any very developed ground infrastructures, they can make speedy progress in setting up space systems for their telecommunications and television networks (as Indonesia, for example, has already done).

Thus a very substantial market will develop. It is to a great extent the existence of that market which justifies our efforts to achieve autonomy in terms of launching materiel, but we must become competitive with the American launching facilities, i.e. the shuttle. This problem of becoming competitive, applicable equally moreover to launchers and satellites, will predominate in the coming years, and fierce competition must be expected.

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France and Europe are handicapped in this regard by the narrow nature of the captive market due in particular to the lack of military space programs. This handicap can only be offset by pursuing a vast research and development effort (for the technologies must still be developed to a considerable extent), supporting industry and attempting to promote a more effective industrial organization on the European level.

In a general way, the methods of European cooperation will probably have to be modified, moreover, in order to face up to the competition in operational systems.

Bio-Agronomical Research

1. Bio-agronomical research involves about 1,800 researchers (full-time equivalent) distributed among the INRA [National Institute for Agronomical Research] (1,100 researchers), the CNRS (700 researchers), the engineering schools, the CNEEMA [National Agricultural Mechanization Studies and Experimentation Center], the technical institutes and agro-food enterprises.

In terms of agricultural assets, this personnel is only a half or a third of that in our main competitors (United States, Great Britain, Netherlands). To this must be added 800 researchers working overseas within the structures of the ORSTOM and the GERDAT [Studies and Research Group for the Development of Tropical Agronomy].

This apparatus, on an excellent scientific level, is unfortunately too widely dispersed geographically. This situation is due in part to the diversity of French agriculture and the size of the various regions, but also to scattering imposed in the name of inadequate implementation of the territorial development policy.

2. Once a net importer of farm products, France has become the second-largest world farm export nation, thanks in particular to research on grains (12 billion francs surplus). In the past 30 years, corn production has been multiplied by 20 and wheat yield has increased by a quintal per year thanks to more productive varieties and the development of new cultivation techniques.

3. Certain research sectors, on the other hand, have been neglected, for example that pertaining to wood. The INRA has developed high-quality research in silviculture. But they have had little to do with the low productivity regions which account for half of the national territory (mountains, garrigue). The import of wood and paper worth nine billion francs is in large part the result of inadequate research on management models, exploitation techniques and above all the development of timber.

4. With energy costs, the undesirable consequences of modern production methods have become apparent. They, among other factors, have led agriculture, once a relatively independent producer of renewable raw materials,

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into dependence, which can be dangerous, with regard to oil products (fuels-fertilizers) and imported raw materials (two billion francs per year for soybeans, coming basically from the United States). However, since 1968, major research has been undertaken, placing our country among those which have studied the alternatives to American soybeans most thoroughly. In fact, the ecological conditions in our country do not justify much hope of producing massive quantities of this crop one day. As of the present, the results of this work (selection of improved varieties, such as the new colza strains, use of urea, more rational exploitation of flatland and mountain pasturage, reduced consumption) make it possible to foresee a 50 percent reduction by 1985 in the volume of our protein imports, representing 85 percent of our animal feed needs. In pedology, which is traditionally one of the strong sectors in French agronomical science, the research effort has not increased in recent years. Knowledge in this sector makes it possible however to make better use of chemical fertilizers (2.5 billion francs in imports) which are factors in costly production and pollution. On the other hand, research on farm mechanization is very weak and poorly integrated with biological research, although this industrial sector is the second-largest branch in the mechanical industry and the reduction of energy consumption can only be produced by proper cooperation between the researchers in the engineering sciences and those in the life sciences.

5. The advancement of this new agriculture, more autonomous and economical, and with optimal biological added value, requires the development of basic research in microbiology of the soil in order to explore the synthetic processes of atmospheric nitrogen fixation to replace nitrate fertilizers, on photosynthesis, physiology and genetics, in order to create new more resistant plants and better to convert solar energy, and on more complete utilization of the resources of regions with low productivity and increased use of all wastes and byproducts, as well as reduction in production losses. In all of these fields there are research teams which are dynamic but still quite inadequate to provide a response to these problems as a whole. Moreover, our lag in the veterinary sciences should be stressed, since the losses are considerable (more than 400 million francs from brucellosis alone) and this situation is a hindrance to the export of our breeding stock. Finally, systemic and synthetic research on the various types of agricultural exploitation which French farming comprises should be broadly developed to derive the fullest benefit from the natural production factors and synergies existing among the various types of vegetable and animal production.

6. The establishment abroad, in the United States in particular, of powerful industries to supply the agricultural sector threatens to pose serious problems for our country. These industries are making an effort to become the sole beneficiaries from the results of research on genetics, micro-organisms, cultivation systems. In France, these industries are very poorly developed and their contribution to the national scientific effort remains very small.

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The improvement of the creative and competitive capacities of our French agricultural and food industries and the industrial branches affiliated with them is evidently a national requirement. Unfortunately, the research in this sector (turnover of 170 million francs) is still on a very modest level despite the efforts of the INRA. The IAA [Food and Agricultural Industries] are putting only 0.4 percent of their added value into research, and are heavily dependent on foreign sources for their processes and their equipment. The government authorities are trying to help them establish powerful research and development centers by category (Clermont-Ferrand for meat, Rennes for milk, Bordeaux for fats, and Nancy for beverages) which they currently lack.

Between now and the end of the 20th century, the energy crisis and environmental protection will give rise to a new industry for the useful processing of all byproducts of farm, forestry and industrial activities. The diversity of technologies to be used will demand much concerted effort by the enterprises and research centers which have previously been a part of relatively different economic sectors.

7. Finally, the absolutely priority role played by tropical research teams should be stressed. They are faced with a delicate redeployment problem because of the gradual nationalization of their research stations in Africa and the competition of the international agronomical research institutes maintained by the British. The impact of France in the Third World, the development of its exports and access to certain raw materials depends to a considerable extent on their success, not to mention their role in the development of scientific knowledge (theory of evolution, for example) and their truly cooperative nature.

#### Data Processing, Electronic Components and Industry

The research personnel in this field comes to about 2,000 individuals for the public sector (full-time equivalent) and 22,000 persons for industry (researchers, engineers, auxiliary personnel).

1. Data processing (1,100 government researchers, 3,500 in industry), which includes basically computers and automation, is a recent field which is expanding very rapidly, and its penetration into the economy and society as a whole is effecting profound changes. It is expected that the weight of the computer industry will be greater than that of the automotive industry by 1985.

In the first section, we stressed the quality of the scientific production of the government laboratories. Much more recent industrial research in data processing, on the other hand, is regarded as of lower quality, with a few exceptions in the peripheral computer sector.

Research is well structured and coordinated on the national level as well as thematically. However, if automation has been able to establish close links

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with the consumer sector (professional centers and enterprises), such links are mediocre and inadequate in data processing, with some changes moreover occurring in industrial strategy. Efforts are currently being made to encourage industry to rely more directly on the government laboratories.

In terms of the country's needs, the research potential remains overall insufficient, despite everything, and the material resources for public research are too limited. To strengthen our position, the automatic data processing sector has been given priority support within the framework of the Seventh Plan and the development of data processing applications (Council of Ministers, 6 December 1978). The priority activity for which the Seventh Plan provides made it possible to create researchers' posts more rapidly than is the average for research in general, i.e. at five to six percent as compared to three percent. This has allowed the development of the existing focuses of research and improvement in the utilization of research results.

The plan for the development of applications of data processing, while its priority goal is the better integration of data processing in all fields, will also permit the strengthening of basic research and that necessary for future applications, both in the public and industrial research sectors.

2. Electronic components (500 government researchers, 3,000 in industry) are in the chain of users of condensed matter physics, the international quality of which has already been mentioned.

Scientific evaluation reveals good-quality work in a certain number of fields, such as power semi-conductor components, integrated sapphire or electrooptic circuits, but also there are inadequacies and total gaps. Certain weaknesses have their origins in a distaste in the government laboratories for certain work as too industrial, but basically they are due to the resources which have been too limited to allow effective pursuit of research involving complex, developing and costly apparatus.

Government research is faced with an industry of strategic importance, the world development of which will be considerable, but which has experienced serious difficulties (integrated circuits), along with less critical fields such as passive components or discrete power semi-conductors. This industry is based on solid physics research and research in technology.

For integrated circuits, the work undertaken on the industrial level (establishment of five centers: the EFCIS [Special Integrated Circuits Studies and Production], SESCESEM, RTC, St Gobain and MATRA) and on the government level (creation of a specialized CNET center and increased support with reassignment of CNRS-university researchers up the line in integrated circuit studies) should guarantee better mastery in this sector.

For the other components, the general activities will be continued with an increased effort in the realm of passive components (machines, production and technology) and the pursuit of the effort undertaken on both the research

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and industrial levels for electronics materials with the EAC, CRISMATEC and Rhone-Poulenc.

3. The electronic industry (about 500 government researchers, 14,000 in industry) includes the following activities:

The consumer goods industry (major public electronics, radio, television, electroacoustics, with a 1976 turnover of four billion francs). This industry has developed a serious commercial lag behind the market as a whole, although technically the enterprises were capable of keeping up with this activity. An improvement in the situation has been seen, although such sectors as electroacoustics (high fidelity) and tape recorders seem to be seriously jeopardized.

These industries must deal with replacement of equipment between now and 1985, but also they must prepare for a generation of new products (second-generation watches, video games, video discs, teleprinters). A recent analysis justifies the hope for an improvement in foreign exchanges, in which an imbalance could develop if the industry does not make an immediate major effort.

The equipment goods industry (excluding data processing, electronic and medical instrumentation) involves basically industrial electronics and the equipment for telecommunications activities.

These activities, involving a turnover of 17 billion francs in 1976, include electromagnetic and optical detection, navigational aid equipment, professional radio and television equipment, radio telecommunications and telephone equipment.

This sector, and in particular industrial electronics, exports actively. It devotes a major part of its resources to research and development (23 to 25 percent in industrial electronics). Recent work confirms French quality and industrial competence. However, some sub-sectors which are heavy exporters (television, aerial navigation, simulation), which are no longer receiving orders or study contracts from the French administrative departments, may find their situation jeopardized. Activity in these sectors has been approved by the government.

#### Scientific Instrumentation

Scientific instrumentation, necessary for research, which must have the most modern and high-performance apparatus, which in turn is based on the research work in all basic sciences (physics, chemistry, mechanics, materials), is also and above all an industrial activity.

It can be estimated that three to four hundred researchers devote a part, generally limited, of their time to work connected with scientific instrumentation. The quality of some of this work has led to remarkable achievements (the work of Professor Castaing, for example).

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The scientific instrumentation industry barely existed in 1964, at which time it was decided to launch a concerted effort in this field. In 1972, there was still a serious imbalance in domestic market supply (25 percent French equipment). Since then this rate has advanced rapidly, reaching 43 percent in 1977. This result was basically achieved thanks to the transfer of government research results to industry. French products, of which 50 percent are exported, bear witness to the rank achieved by our country: holographic networks, Raman effect spectrometers, Raman microsondes, electronic or ionic sondes, etc.

This position remains weak, however, and requires strengthening and stabilization, if an industry the importance of which, in terms of independence or as a factor in development, vastly exceeds its own turnover figure, is not to disappear.

Biological and Medical Engineering (GBM)

The growth in earlier years (1970-1976) is interesting to observe. Between 1970 and 1973, production growth was 8 percent and market growth 14 percent, resulting in a rate of coverage in France of less than 70 percent, for the "medical electronics" sector as a whole. The situation improved a little between 1973 and 1976, making it possible to increase the average growth rate to 17 percent and 19 percent, respectively, for the period 1970-1976. During the same period, in the medical-surgical instruments field, the production growth and market growth rates were equal, at about 20 percent. This field gives a satisfactory impression of stability, but its fragility, above all in lower-range products, is a fact.

In the years to come, a growth rate of 10 percent for medical, electronic, radiological and biological analytical instrumentation can be expected. Where medical applications of ultrasonic or laser beams is concerned, a 20 percent growth rate can be expected. Certain sectors such as ophthalmology will perhaps experience still more forceful growth. A number of arguments justify this optimism: the limited role played by equipment expenditures in health costs, the financial desirability of replacing human effort with new equipment, probable development of new instrumentation, the equipping of the countries in the process of development. Other arguments dictate greater caution: general reduction of expenditures in the industrialized countries, planning regulation of heavy investments, at least in France.

This very brief growth analysis suggests that if the production growth rate is maintained in the 8 percent range, we would have a rate of coverage of about 60 percent toward 1980, which would substantially aggravate our foreign trade deficit. Thus it is necessary to increase this rate to 16 percent, which is practically impossible in the sectors already exploited, and thus a policy of research and innovation, either in notably neglected sectors or in new ones, is imposed upon us.

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On the initiative of the DGRST, a broad effort has been underway for some months now. It includes the establishment as of 31 January 1978 of a biological and medical engineering coordination committee. In addition, five joint action committees have been established: for analysis in clinical biology, for image analysis in biology and medicine, hyperthermia, new GBM techniques, and lasers in biology and medicine. The DGRST budget for GBM increased from 5.5 million francs in 1977 to 8 million francs in 1978. In addition, the establishment of a national laboratories and industries master file with a GBM section is in progress. Finally, the development of regional GBM centers is likely to have a desirable influence on national and regional structural development. Following the 27 January 1979 meeting of the GBM coordination committee, it was decided to recognize the following centers, initially:

1. Rhone-Alps center, serving both the Lyons and Grenoble areas;
2. Lille and Toulouse center; and
3. Nancy center.

The situation of the Montpellier region, just recently evaluated, will be discussed later.

Finally, where the Paris region is concerned, its potential was recognized but lacking a coordination project, recognition of a center will await evaluation meetings held jointly with the bodies involved. The establishment of these centers justifies the hope of clearer motivation toward GBM research, indeed the elimination of the marginal nature of this specialty. It will undeniably encourage relations among doctors, industrialists and scientists, which are still very limited at present. The role of the AEC in this structure will remain basic. That of the INSERM will increase.

On the level of industrial and commercial advancement, the development of prototypes is to be recommended, along with their analysis in efficient evaluation centers prior to their introduction in hospitals, and then export, with all the difficulties this involves where PME (small and medium-sized businesses) are concerned.

On the research level, activities should be focused on specific programs, encouraging the training of high-level researchers with official recognition of the discipline on all university levels. The number of biomedical engineers in the hospitals should be very substantially increased, for they are indispensable links in the system. The INSERM should be encouraged to strengthen its potential by expanding its accommodating structures and promoting the establishment of a French GBM periodical. Finally, serious information studies and prospecting of foreign markets should be undertaken.

On the developmental level, it has been decided to establish an advisory committee on medical instrumentation, analogous to that operating

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satisfactorily in the data processing sector. It seemed necessary to insure close coordination of the activities with those of the National Hospital Equipment Center, and to undertake an in-depth review of hospital supply systems, technical considerations and, in addition, to very seriously contemplate industrial reorganization, above all in the sectors where PME dominate heavily, such as to consolidate their fragile financial structure, improve their trade network and to resolve, probably in their stead, the difficult export problems. If certain sectors are worthy of being studied and maintained, others should benefit from growth contracts--ultrasonic and laser equipment, biological analysis, ECG [electrocardiograph], ophthalmology, etc. are included here. In addition, some sectors lend themselves to new undertakings--heart pacemakers, hearing aids, etc.

Chemistry

As an industry and as technology, chemistry plays a role in the great socioeconomic pursuits such as health, agriculture, environment, processing industries.

a) Where health is concerned, it is now unthinkable to be content (at what price!) with trying to utilize the new molecules in the various medical fields, in the hope of finding an interesting one. Ever-greater numbers of chemists are turning to molecular biochemistry to understand and mechanisms of the action of molecules in a living organism, and to predict the type of molecule necessary to act on any given pathological irregularity.

Pharmaceutical innovation is the product of multiple cooperation among the scientific specialties, but also between research and engineering in organizing the transfer of knowledge. It is to the basic researcher that the task of reformulating problems and methodology and training cadres for research in sophisticated techniques and reasoning falls. But at the other extreme, industry alone is in a position to master the technological aspects of development, thanks to its organization and logistics.

The importance of medicines in industrial societies justifies doing everything to reconcile the economic limitations (the cost of an innovation is doubling every two and a half years), scientific requirements and adaptation to the often contradictory needs of public health.

b) France has major farm resources, and its chemists should make an imaginative effort to establish what kinds of industries could be based on our agricultural resources. Cellulose and sugars could be supplied in abundance.

Since we have neither raw materials nor cheap energy sources, chemists should also mobilize a research effort on processes of assimilating nitrogen for fertilizer production.

c) Combating pollution is increasingly seen as the duty of chemists, who alone have the capacity to wage the struggle rationally. Given the known

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difficulties of processing waste water in small units, where it is difficult to place a competent chemist, and only 15 percent of which, it is readily admitted, are effective, this crucial problem should be reviewed. It is important to be able to have available soon units which can function suitably without highly specialized manpower. Similarly, chemists should make an effort to direct their research toward the so-called "clean" processes, i.e. those which produce relatively little pollution.

d) Within the framework of the processing industries, the chemical industry should, in terms of its economic context and taking our limited natural resources into account, develop production with high added value, in order to offset the deficit in pure chemistry. Also, it should work on the exploitation of ever poorer ores, requiring basic and applied studies.

In view of these needs, and many others as well, government and university research in chemistry seems to be very unequally distributed today. Research of excellent quality is found side-by-side with the work of many teams which are relatively unstructured and have purely academic concerns, while subjects both more interesting and more useful are inadequately dealt with and in the engineering sciences, much--and sometimes almost everything--remains to be done (chemical engineering is an example). As to industry, if research is substantial in numerical terms (5,000 researchers and engineers, more than 3 billion francs), it has focused its effort in particular in recent years on real innovation, but to achieve this should rely more on basic knowledge.

In the course of the past 20 years a definite improvement in the level of research has been seen. This effort must be pushed still further, for if chemistry was one of the sectors most dependent on research results in the past, this dependence is now even greater, given present and future economic circumstances.

#### Mechanics and Processing Industries

Mechanics, the materials sciences, lie at the base of a complex of so-called traditional industries. But this relation is only partial and its scope should not be exaggerated. If it is useful, in evaluating sciences and technologies in terms of industrial problems in these sectors, to assign a special place to research in these disciplines in the government and university laboratories engaged in such work, an effort should also be made to evaluate to what extent research as a whole is in a position to prepare for the future of the industries involved.

In fluid mechanics, it is possible to rely on the scientific quality and the capacity for transfer to industrial needs. The government research potential is of sufficient volume, and some new goals can be suggested for it:

Promoting the use of scientific advances in fluid mechanics by traditional industries which have made little use of science (classic equipment goods, textiles, paper), which will require an effort to establish dialog with the design bureau engineers for the analysis of their technical problems in scientific terms; and

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Development of work oriented toward environmental problems--the spread of pollutants, atmospheric development, the generation and dissemination of noise, and thermal wastes from nuclear plants.

In solid mechanics, on the other hand, university circles are still for the most part ill adapted to industrial needs. A certain positive development can be noted thanks to the joint efforts of the DGRST and the CNRS, but it involves only a still marginal portion of the teams. A major effort should be made in two directions:

Definite redeployment of the university potential toward scientific work related to applied problems, relying on the structures which are already engaged in directed research (AEC, ONERA, engineering schools) and on the few teams already well focused; and

Making a larger number of industrial enterprises (in particular PMI [small and medium-sized industries] and traditional sectors) more aware of the importance of scientific advance to the understanding and resolution of their technical problems.

In the materials sciences, a certain optimism is justified for metallic materials, for the potential, satisfactory in volume and in quality, is rather extensively applied in industry. On the other hand, research involving other widely used materials (plastics, ceramics) is clearly inadequate and ill adapted. The teams are few, the industrial sector is unreceptive, and the researchers are too much limited to basic and single disciplines.

Perhaps nowhere more than in these disciplines is the dichotomy between researchers and engineers more harmful. Encouraged by the separation of the training systems (engineering schools on the one hand and the universities on the other), the two parts of a single problem have thus developed independently.

From the point of view of the French economy, mechanics and the materials sciences play a determining role in all industrial sectors, and not only the enterprise classified under "mechanics and processing industries." All industries have need of high-performance equipment goods and thus rely on mechanics.

In particular, where the traditional sectors are concerned (leather, publishing, printing, paper, textiles, furnishings), it can be noted that an industry which shuns innovation is doomed to disappearance sooner or later. Innovation does not mean research alone, but also involves knowledge of the market, capacity to sell, adaptation of financial policy, etc. But research is necessary for the understanding of the phenomena and processes of production, and thus the ability to change them. This is what has produced the success of such enterprises as Creusot-Loire, Michelin, Leroy-Somer or Moulinex, which have never ignored any research or development factor which

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could possibly be useful to them, and which are continuing to develop within a difficult context. This is what is lacking in the sectors experiencing difficulty--leather, wood, paper, textiles, metallurgy, publishing. All of these sectors are devoting less than one percent of their turnover total to activities related to research, and this is often done through technical centers which sometimes do remarkable work but which are most often poorly adapted to the problems of specific industries, are rather rigid, and scientifically relatively unproductive.

In conclusion, what is needed is not only a greater and better-oriented government research effort, but also a change in the habits of industries and technical centers.

#### Research and the Goals of Society

##### Medical Research

Medical research, so limited 25 years ago, currently enjoys an important potential in personnel and resources in our country. The level of researchers has risen astonishingly. The distribution of tasks among the various bodies is flexible. They vary in dynamism. The INSERM shows excellent growth; the Pasteur Institutes have reestablished their financial balance and their work is efficient; the reorganization of the CNRS and the work of the research mission at the Ministry for Universities will be the basis for further upsurge. However, the tasks to be carried out are enormous as a function of the demands of our society and its requirements in this realm. It is obvious that in relation to the overall expenses in the health sector, the allocations for research are inadequate, lower than for any other sector of our national life. It is for each individual to judge if it is wise to accept this distortion or whether it needs gradual correction. Medical research serves the purpose of protecting the health of man by preventing, correcting or alleviating the problems which affect him. Medical research has its expression in three sectors: clinical studies, public health research and biomedical research.

##### Fourth and Fifth Plans

In the course of the Fourth and Fifth Plans, the authorities in the medical research field, just emerging in fact, analyzed its results and planned their efforts as a function of the classification of research based on the classification of medical specialties and organ pathology. Physiology, biochemistry, regulation, morphology and therapeutic technology pertinent to a given organ would then be grouped around the study of clinical pathology. Some examples, still current, are of interest because they show the very great differences in success in our country in this type of procedure for planning research.

The research in our country on ailments of the kidneys and urinary tract, diseases of the digestive tract and related organs, on hematological problems

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and on endocrine gland anomalies enjoy an excellent international reputation. Diseases of the respiratory system and the nervous system require encouragement and reorientation. Certain sectors, despite efforts to encourage them, remain very poor: odontology, orthopedics, dermatology, ORL [otorhinolaryngology] and ophthalmology. As of 1979, measures to encourage these sectors are being undertaken in the form of contract-programs between the DGRST and public bodies.

Sixth and Seventh Plans

Beginning with the Sixth Plan and during the Seventh Plan, the major thematic guidelines and priority sectors have been established as a function of the major causes of mortality and morbidity in man. This plan has yielded interesting results.

Biology and the Development of Reproduction

Research in the biology of development and reproduction has brought astonishing results in the protection of mothers and infants.

The success is great, for perinatal mortality has dropped from 23.4 per thousand to 16 per thousand in 7 years, an important fact in this period in which a declining birth rate creates great concern about the future of our country. The problem is still more important where chronic children's diseases and deficiencies which are factors in handicaps are concerned. It is estimated that about a million children in our country are affected by a motor, sensory, mental, general or multiple handicap problem. The current cost to society accounts for at least two percent of the gross national product, without a doubt. The affective, social and economic consequences for the many families affected are considerable. Now at least half of these handicaps are related to hereditary anomalies, chromosomal aberrations, or congenital malformations due to early illness in the embryo, or foetal or neonatal damage. Rapid progress is being made in understanding them, early detection and sometimes prevention, and already the percentage of handicaps of prenatal and perinatal origin in certain regions of our country is dropping rapidly. However, progress remains to be made in the realm of perinatal studies and protection of the foetus. Research on obstetrics remains very inadequate despite real effort. The goal for the years to come is now a serious problem, that of congenital malformation, which affects two percent of the live-born infants. This is creating an ever-heavier affective and economic burden for society. Prenatal detection of such malformations has progressed greatly thanks to amniocentesis and the use of echograph techniques. The epidemiology, mechanisms and possible means of preventing these malformations require better understanding.

Cardiovascular Ailments

These represent the leading cause of death, i.e. 40 percent, or about 20,000 individuals each month.

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French scientific production has reached an excellent international level in a number of fields: basic myocardial biology, analysis of rhythmic difficulties, arterial hypertension, synthetic understanding of the arterial wall, mechanism of thrombogenesis, instrumentation (electrophysiological equipment, prostheses, pacemakers and echography equipment), study of the renin-angiotensin system. The results achieved in the study of certain factors in arteriosclerosis and in pharmacology are more limited, and in epidemiology, weak. International exchange is very good and a number of French laboratories enjoy a very good reputation. It is clear that the importance of this sector is such that research in it should be developed in the training of personnel and in terms of laboratories and equipment. Biomedical research must rely on the rejuvenation of clinical studies and above all, on the development of public health research, which has been most inadequate in this field of heart and blood-vessel ailments.

Tumors and Malign Hemopathy

These ailments are the second most important cause of death in France, accounting for 20 percent. At present, more than one cancer out of three is being cured.

Cancerous ailments, disturbing the life of the cells and cell populations, has been the subject of research both very basic (molecular and cellular biology, developmental biology, immunology, genetics, virology) and applied (etiology, diagnostics, therapeutic techniques).

France, with 600 researchers, has played a competitive role in research fields in recent years--in studies of oncogenic viruses, on the basis of an agreement between the INSERM and the NIH [National Institutes of Health], which has yielded excellent results, immuno-oncology, the genetics and cytogenetics of cancer, cellular kinetics applied to oncology, immunotherapy, chemotherapy for solid tumors and leukemias and the new radiobiological techniques. It is necessary to support the most active French research sectors in this field, to increase the resources for cellular kinetics and chemical carcinogenesis, in which activity is slowing, and finally, to expand the potential in epidemiology, which is of excellent quality but has inadequate resources, and research on detection and prevention.

Neurology and Mental Health

The burden placed on our society by psychoneurotic ailments is considerable: 120,000 hospital beds almost 100 percent occupied, accounting for a third of the public hospital facilities. It becomes obvious that the material burden placed on the collective by problems of the higher nervous system accounts for an appreciable fraction of the gross national product, two to three percent at a minimum, probably more.

Research in neurobiology, which we have already discussed, has made possible reasonable progress in neurology. Neurochemistry and genetics and the study

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of animal models has made possible major progress in the realm of hereditary ailments of the nervous system. Neuroanatomy is less well situated. Studies on slow viruses and plaque sclerosis have been the focus of recent efforts in France. The introduction of new molecules in the treatment of neurological difficulties as well as the development of neurosurgery should be noted. Except for a few teams, however, the lack of vigor in applied research in this sector can be noted, contrasting with the excellence of French teams working in basic neurobiology. Inadequate contact between clinical workers and basic researchers is perhaps a factor.

Research in psychiatry poses still more difficult problems. The maturing of the French psychiatric environment has created uncertainty about the rapid establishment of research in this sector. The conference on psychiatric research held in Royaumont on 21 and 22 January 1977, and the 1976 efforts of the Work Group of the Specialized Commission of the INSERM, set forth however possible lines of action. We should note the satisfactory development of the French teams in the realm of psychopharmacology, where for some years they have played a leading role on the international level, and the remarkable efforts made by some teams in our country in analyzing the psychotic components of mental retardation, and studies of relations pertaining to patients, and the psychiatric consequences of congenital sensory defects. The analysis undertaken with regard to neurobiology underlines the importance of the "neurosciences" concept. It is on the basis of this concept that mental health research activity should be undertaken within the DGRST, with a view to developing the gradual organization, despite the present contradictions and shortcomings, of comparison and coordination in this field.

The Biology of Man

Human biology in its development and the health problems pertaining to it have of course been the focus of major research, with considerable priority for the biology of reproduction and development and the protection of mothers and infants. But for lack of pushing the concept of development far enough and extending the concept to death, a number of aspects have been neglected. It is clear that basic research and applied medical research on aging are quite inadequate. Studies have concentrated mainly on illnesses developing in the elderly as well as the treatment of them, but very little on the mechanisms of aging in the higher animals, nutrition and pharmacology for the aging, and to an inadequate extent, on the mental health of the aged. This is not exclusively the problem of the more privileged societies, but exists in the countries in the process of development as well. A number of French teams are working on it. But here again the development of research is not proportionate to the importance of the problem.

Public Health Research

The development of prevention, detection and future planning in medical activities makes the encouragement and coordination of public health research, lagging badly in our country in comparison to the majority of the others, urgent. However, for 10 years now, the redirection of certain teams, the

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establishment of a number of public health units, and the training of high-level researchers has justified expectations of a rapid upsurge in this sector. The launching by 1980 of a concerted DGRST program which is under study is to be hoped. "Public Health Research" will to begin with have three main sub-aspects: epidemiology, research on the economy and structure of health systems, and two-way interaction between psychosocial environment and illness.

## Pharmaceutical Research

The goal of this field is the development of medicine. This is research applied to the health of man, but also that of animals and plants. The various disciplines involved in the pharmacological chain are molecular pharmacology, cell experimentation (cellular pharmacology) and experimentation with animals (pharmacodynamics), and finally, clinical pharmacology in its various aspects: pharmacokinetics and biotransformation, therapeutical experimentation, drug supervision and pharmacotoxicology.

Public research is pursued above all by the universities, the CNRS and the INSERM. It is difficult to assess the public resources in this sector exactly: about 230 researchers at the CNRS and 260 at the INSERM, with an equal number of technical workers. Our drug industry ranks fourth in the world (after the United States, the FRG and Japan), and accounts for one percent of our gross national product. It devotes 10.2 percent of its turnover total to research and development, of which two-thirds is research as such. The positive overall balance for the French industry quintupled between 1968 and 1977. However the situation in pharmaceutical research reveals some elements of concern. In the public sector, the insufficient number of qualified pharmacologists is a fact in pharmacokinetics and biotransformation in man and animals, in pharmacotoxicology and in clinical pharmacology. In the private sector, the lack of long-term research is obvious, economic factors being limiting. The Economic and Social Council recommended in January of 1978 that special attention be devoted to pharmaceutical research. Three measures have been pursued at the DGRST: a policy of training scholarships which is currently inactive for lack of a sufficient number of openings; concerted activity on "new medications"; and the establishment of a study group responsible for proposing timely solutions in medical and veterinary pharmacy in the short and medium time range.

In clinical pharmacology, it is necessary to develop hospital-university posts and medication commissions in the hospital, specialized training for clinical workers in the differentiated sectors of pharmacology (the aged, pregnant women, the newborn), and to provide better definition for the generally excellent but scattered activities of the INSERM through its free contracts, its temporary allocations and its groups and units. It is important moreover to make broad use of the contract program arrangement between the DGRST and public bodies, the DGRST and private research bodies, or all three together, a formula probably much more efficient in this sector

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than joint action. In this connection, three contract programs have just been included in the 1979 budget. The problem of scholarships must be approached in terms of "training-acceptance," with regard to the public, semi-public and private sectors. Finally, a specific and progressive program for establishing pharmacotoxicology, a sector in which our country is very weak, should be drafted. One center in Lyons a second at the Pasteur Institute in Lille are being built.

## Research on Goals in the Social Sciences

The question of the usefulness or the use of the humanities gives rise to a number of misunderstandings, the main one doubtless resulting from a concept which is too narrow and too non-functional. One of the main roles of these disciplines is to allow society to gain an awareness of itself and to understand itself in its historic and future dimensions. This function, which involves evidence, contemplation and criticism simultaneously, is curiously enough perceived in all its "usefulness" only in the societies where it is forbidden or distorted.

It offers advantages which the public understanding is less likely to miss: more profound study of the contemporary economic and social problems with the prospect of assistance in making decisions. Here again, research in the humanities gives rise to misunderstandings, frequently described and developing within the circle of researchers and also that of administration and decision-makers. The first demands total independence from the existing structures and rejects the a priori description of a goal to be achieved, while the second demands functional solutions and sets itself clearly defined goals. The conflicting nature of these two worlds in which what one wants is seen as an effort at domestication while the freedom of the other is suspected of using up substantial public credit on projects the general interest of which is not always obvious, has led to a situation which both sides agree today is abnormal. While the administrations create their own research bureaus in order to meet their research needs, or turn to researchers who have no status outside the public research bodies, major research in the social sciences is being pursued within these bodies on a semi-confidential basis. This description, reflecting one of the key problems in research in the humanities, makes it possible to understand why the evaluation of "goal-oriented" research in the sciences of man is rather broadly an evaluation of work done outside the existing structures, on the basis of contractual policy and/or carried out by specialized centers placed within the subdivisions of a ministerial department.

If this evaluation is set forth here somewhat cautiously, partially and, finally, somewhat unsatisfactorily, for those seeking to obtain a precise notion of the quality of the work produced and their adaptation to the national needs, it is because the contractual policy in this sector has never been subjected to systematic examination from either of these two points of view. A separate analysis would not serve the purpose here, particularly

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since the lack of an evaluation is not without its reasons: far from constituting a consistent research whole achieved by homogenous and clearly identified teams, on subjects clearly defined on the national level, contract work on sometimes general, sometimes specialized work is entrusted by scattered demand centers to diverse teams, unequal in size and varying in status, for which the contract resources can only account for a fraction of their total.

The effort made is thus of a modest nature, describing the most obvious virtues and shortcomings for each main sector.

In the realm of developmental construction, it seems necessary to set forth the architecture program of the CORDA and the humanities sub-program of the Construction Plan. The urban development campaign achieved interesting results (establishment of a specialized scientific circle, satisfactory relations between the administration and research sectors) but the scientific production remains subject to its traditional law: prolific, chaotic and non-cumulative.

In the "work-training-job" sector, the general delegation launched two campaigns, the initial results of which are encouraging. One has to do with the relations between training and jobs, and the other with labor conflicts. A third campaign seems already doomed to failure. It pertains to women's labor, and for the purpose the existing work force seems most inadequate. According to its guideline document, the CORDES [Committee for the Organization of Research Applied to Economic and Social Development] is interested only marginally in the subject of education, but is involved in various research projects in the labor sector. The CNRS has pursued an ATP [planned thematic action] education program for several years on widely scattered subjects involving both apprenticeship methods and the educational apparatus, teaching institutions and job relations. The goal was to develop the educational sciences and enable France to catch up with England and the United States. The goal was not achieved.

In the sector called "socioeconomics of health," research still seems ill adapted to the needs. The INSERM has not adequately incorporated this concern, and if the activities of the CNRS and the DGRST in this field show very positive features, the research effort they represent remains inadequate in view of the importance of the sector.

In the realm of human ecology, the research done on the initiative of the DGRST has made it possible to launch a fruitful dialog between the life sciences and the humanities. But this research must be vigorously pursued in order to interrelate the scientific knowledge indispensable to the development of low-productivity regions.

In the realm of deviation, crime and delinquency, the situation is hardly satisfactory. The contracts signed within the framework of the Ministry of Justice are short term and often deal with very limited subjects. As to the

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campaign on the "social control of deviation" pursued by the DGRST, it does not currently justify hope for more than very partial results. The Peyrefitte report recently stressed the lack of adaptation of this research sector to the national needs.

In the field of the macroeconomy and aid to planning, the work done is mainly on the initiative of the CORDES, which has made this one of its dominant concerns. These efforts seem widely scattered and little related to the goals of planning. Two programs undertaken by the general delegation in 1976 in the macroeconomy sector, on "growth and employment" and "the international division of labor" both appear encouraging at present.

Research on goals is also the task of specialized departments within the framework of a ministry. From this point of view, the research on population problems pursued by the INED is useful and of good quality. The research on farm production and the rural sector pursued by the INRA is on a proper scientific level but is being developed in too isolated a fashion. The research on the countries in the process of development undertaken at the ORSTOM suffer from scattering of the areas but the quality is generally satisfactory, except for the studies involving urban research and education systems, having to do with basic problems in the countries in the process of development. Finally, in the realm of juvenile delinquency and criminology, the research done at the centers of the Ministry of Justice for supervised training and educational research are very classical in nature and far from the concerns of the ministerial departments concerned with penal and criminological studies.

Environment

The environment is not a discipline, nor is it properly speaking a research sector, but rather a concern to be taken into account in a number of fields.

Thus there are but few public or private laboratories devoted exclusively to environmental problems. Basically, it is necessary to rely on a research potential found in a large number of bodies and pertaining to a variety of disciplines.

From the point of view of quality, considered in terms of that of the teams which could potentially be mobilized, the situation would appear to be fully satisfactory. Apart from a few very inadequate disciplines (such as toxicology), there are a sufficient number of laboratories and high-level teams. The capacity to mobilize numerous high-quality teams however is in fact lacking. There are a number of reasons for this difficulty: the stress placed to date on excessively short-term goals; the fact that the structures and the traditions of the bodies do not encourage the careers of researchers who choose to devote themselves to environmental problems; and finally, the general difficulty in establishing and pursuing multi-disciplinary research. From this point of view, the incentive methods of the Ministry of Environment and Human Ecology, as well as multi-disciplinary programs such as those of the PIREN at the CNRS have already begun to improve this situation.

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Also, some qualification of the present situation is merited in its assessment. In comparison with the other countries experiencing similar difficulties, our situation, moreover, is not unfavorable, and French contributions are very often sought in these fields.

It is not really possible correctly to evaluate the adaptation of research to needs unless the goals are clearly and correctly defined. At present this still remains to be done. If certain social movements seem to presume that there are solutions to all problems, and that all that is lacking is the will to implement them, the responsible bodies on the level of the public administration should not on the other hand tend excessively to undertake research toward short-term goals of reducing or eliminating pollutants, most often involving known technical solutions.

Now the role of research is to prepare for the future, even more than to correct the present. What should have priority then is the definition of a new plan for research, setting forth very clear medium- and long-range goals.

It should then be possible, through suitable changes and amendments in structures, to mobilize a quality potential toward these goals.

Developmental Activities

The developmental sector includes a complex of activities occupying 20 percent of the active population. It includes construction, civil engineering, urban development and transportation (aeronautics, naval construction, railroad transportation, automotive sector). The research pertaining to it is obviously distributed among a large number of disciplines and technologies. The volume thereof is estimated at 5.4 billion francs (1975 figures), i.e. about 20 percent of the research and development expenditures in France.

However, this figure should not cloud the reality. It is focused basically in two industrial sectors: aeronautics (3 billion 200 million francs financed for the most part by the state) and the automotive sector (1 billion 600 million francs) and represents for the most part developmental activities pertaining to industrialization. Research as such, that which prepares for the future, is weak--too weak--in this sector. The responsibility for its financing falls mainly to the government authorities, but apart from the specialized organizations (CSTB [Scientific and Technical Building Center], LCPC [Main Highway Department Laboratory], ONERA [National Office for Aerospace Studies and Research]), it has been difficult to date to interest large research bodies (such as the CNRS) or the universities in these problems.

In the realm of scientific and technical achievement, a wide gap exists between such fields as aeronautics, automotive vehicles, rolling stock and civil engineering, in which the advance is notable, and building and naval construction which have not yet reached scientific dimensions. This hierarchy is also seen in the United States, Japan and the FRG, with some variations in the maritime and railroad transport sectors.

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Among the general difficulties we might note the underdevelopment of basic research and the lack of liaison among the various stages of research, the weakness of certain disciplines (mechanics, electrochemistry), and the lack of continuity in support of the government and private technical laboratories.

In the course of the coming period, this sector will have to pursue three goals: development of production and maintenance of employment, reduction of energy dependence, and establishment of conditions favorable to the development of the French economy and society as a whole. The capacity of French research to respond varies with the fields of activity.

In the building sector, the highest-level scientific potential is found in the government bodies and professional technical centers, which will allow very favorable development on the level of service quality, reduction of energy consumption and renovation. On the other hand, the business enterprises are far behind, which augurs badly for the winning of foreign markets.

The civil engineering sector is experiencing economic problems similar to those in building, but has some enterprises with international dimension. The transfer of knowledge in the realm of quality of service poses no major problems. Competition on the foreign market remains most formidable (little challenge to technology adapted to the French situation).

Aeronautics, in which there is massive support of research by the government authorities, will not long be able to measure up to the competition without increased support of basic research and of the ONERA-CERT.

The automotive sector (exports, labor) suffers from a handicap to the extent that the builders were slow in undertaking long-term planning. However, the potential exists and the state has some hundred quality individuals engaging in evaluation and research distributed among the IRT [Transportation Research Institute], the ONSER [National Road Safety Body], the UTAC [Technical Automobile, Motorcycle and Bicycle Union] and the IFP. Increased mobilization of this complex seems necessary at the present juncture in order to provide a valid response to the limitations dictating the definition of the automobile of tomorrow.

The current potential in the railroad transport sector is not sufficient to keep our industrial products competitive easily. Continued progress on the development of materials and the productivity of production lines is necessary. Service quality has improved considerably both in passenger transport and freight transport and the transfer of knowledge poses no problem.

The problem of mass urban surface transport lies basically on the level of service quality. The scientific potential is limited and disorganized, and the builders of the classic equipment have little motivation.

Naval construction, currently an export sector, utilizes substantial manpower and has a substantial turnover figure. It should be able to redirect

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itself speedily toward the production of equipment of a high technological level, but has practically no government scientific potential.

Research on the utilization of transportation networks and systems has been and will continue to be a basic factor in the development of service quality. Orders from abroad for studies, like those undertaken by the RATP [Independent Parisian Transport System], reflect this quality and lead to orders for equipment, depend on a proper level here.

The socioeconomic importance of this sector has not caught the attention of university researchers, who with but a very few exceptions are not interested in the various problems it poses. A reversal in this trend is occurring more rapidly in foreign countries, particularly the Anglo-Saxon countries, where engineering faculties are better oriented toward this sort of problem.

Scientific Cooperation With the Countries in the Process of Development

In 1979, the cooperative research budget came to 613 million francs, i.e. 4.6 percent of the national research allocation. In fact, this is only a partial assessment, to be supplemented by contributions from other French sectorial budgets and by the secondary financing represented by the counterpart funds of the partner nations (110 million francs in 1979). The ranks of researchers and technicians for the same year came to about 3,400 individuals, including 1,500 high-level engineering researchers. The total accounts for seven percent of the scientific personnel under the total research allocation.

French Research and the International Stakes

Overall, the French scientific effort for the PVD [developing countries] accounts for 60 percent again of the government aid allocated by the 9 EEC countries, but the very rapid increase in the course of the past decade in the joint efforts of the North American and Scandinavian countries has led to an alteration in relative contributions, to the detriment of the French position.

This joint effort by the large industrialized countries derives from the importance of the international stakes, which can be described in terms of the three sectors corresponding to the major goals of research for cooperative purposes.

The first is encouragement of the development of the Third World countries without losing sight of the fact that some of them are as of the present or will shortly become economic and trade partners of leading importance, as the recent but steady increase in economic trade between France and these countries, in particular in the export sector, bears witness.

The second goal is to guarantee a scientific and technical continuation to the classic activities representing the French cultural presence, in particular

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by an increased effort to train young nationals as researchers in order to strengthen the networks of scientific relations and create environments receptive to the purchase and transfer of French technology.

The third goal is of a scientific nature, involving keeping French science open to the diversified and unique research fields pertaining to the tropical world, and to maintain the lead of numerous teams whose results on an international level have led to undeniable repercussions on the level of the French scientific community.

The Geopolitical Context of This Activity

The specific limitations on the framework of activity demand a permanent effort toward renewal and coordination in research activities for cooperative purposes.

First of all, for several years a tendency toward diversification has been strengthened.

First, there is geographic diversification of the partner countries, leading to a redeployment of activities previously concentrated on French-speaking Africa and the DOM-TOM [Overseas Departments and Territories] in the directions of Latin America, tropical Asia, the Middle East and English-speaking Africa.

Second, there is diversification of the sectors studied and the scientific themes taken up, involving a constant adjustment on the level of the teams (competence and specialization, mobility, availability).

In the second place, whatever the partner country may be, it is ever-increasingly a matter of negotiated cooperation, taking the priorities and the goals of national scientific policy into account. Due to this fact, one aspect is becoming dominant--research oriented toward development.

In the third place, the ever-keener competition, manifested most frequently through the large international organizations, is leading to a re-drafting of the overall strategy of cooperation, based in the past on bilateral agreements, inclining it to some extent toward multilateral activity.

The Programs

The analytical framework comprises five major axes of research of unequal importance, themselves subdivided into thematic subgroups.

Understanding and Development of the Environment

This realm, first studied long ago and benefiting from important gains in scientific results, has been developing for some years in two complementary directions: more definite orientation toward territorial development goals and transition from an approach by discipline to an integrated approach focused on an understanding of the ecosystems and the regulations governing their use.

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Improvement of Farm Production

This research axis continues to play a preponderant role in the cooperative research structure, both because of its weight in resources and because of the scientific and applied scope of its results. A number of recent trends should be stressed: rebalancing in the direction of vegetable crop production for food, the products of livestock breeding and fishing; a research approach to production by complete lines, proceeding from general improvement of industrial technology; and abandonment of research by production group in favor of integrated research relating several crops in a single exploitation system.

The Humanities

Research in the humanities and in economics in the developing countries, frequently approached in the past from a basic viewpoint, must now deal with the need for adaptation. Two goals have generally won the support of numerous partner nations and allow the pursuit of sustained activity: response to the economic and social problems posed by development (support of developmental operations, decision-making, and education systems), and the drafting of national cultural policies.

Medical Research

An overall diagnosis of this research axis reveals a series of weaknesses: inadequate functional and personnel resources; geographic and thematic scattering of the programs in progress; and little interest, relatively speaking, in the bodies in the home country in tropical health problems.

An overall effort to create an upsurge focused on priority themes is seen to be necessary along three lines: communicable diseases, nutrition and population genetics.

Technical Research

At the present time, agro-food technology programs play a priority role because of their close relation to research on improving plants and developing the major tropical products. Industrial technological research needs a major effort of diversification and coordination with private research undertakings (technical centers). Finally, urban studies, taken up mainly by the humanities (studies of cities), are very rarely related to the problems of developing and equipping tropical cities.

Training

A recent adaptation and structuring effort should be stressed in the fields of knowledge of the environment and plant improvement (ORSTOM--organization of the DEA [Applied Economics Department], in cooperation with the universities, and creation of the IFARC [Institute for Agronomical and World Training in Hot Regions] within the framework of the GERDAT [Studies and Research Group

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for the Development of Tropical Agronomy]]. Where the other research axes are concerned (humanities, medical research, technical research), tropical specialization is still approached in a scattered and diffuse fashion in terms of the classic university categories.

Adjustment of the Scientific Cooperation Policy--Apparatus and Prospects

The Committee for the Coordination of Research Pursued in Cooperation With the Developing Countries, established at the DGRST in March of 1977, is the central and interministerial body drafting the scientific policy for cooperation.

Specifically, this goal is achieved through four main and complementary functions:

An inventory function for the research and training programs as a whole carried out by French bodies in or for the developing countries;

A general coordination function for scientific activities, in particular on the level of research structures;

An orientation function for the geographic redistribution of activities; and

A final function of providing consistent definition of the thematic directions of cooperative research (procedures in the sectorial advisory groups under the jurisdiction of the committee).

The work of the developing countries committee, examined in overall fashion recently by the CCRST, has made it possible to establish a series of program lines constituting the structural skeleton for scientific policy, and should normally guide the short- and medium-term allocation of budget resources to research as a whole. These program lines are:

Maintenance of a sustained research effort on natural environments, through integrated programs on the tropical ecosystems, in particular;

Selective augmentation of the resources devoted to the improvement of farm products, reflected in particular in an increased effort with regard to the International Agronomical Research Centers (CIRA) and by a supplementary effort with regard to livestock and fishing production;

Maintenance of the research potential in the humanities, in particular in the sectors supporting development;

An overall effort to accelerate, structure and coordinate tropical medical research (advisory group in progress);

A major effort toward a new upsurge in technical research (advisory groups planned for the end of 1979), in cooperation with private research; and

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General acceleration of training effort.

In the longer range, the development of French scientific support of the developing countries inevitably involves a more effective mobilization of the research bodies in the mother country, through a better organization of the specialized bodies (reorganization of the ORSTOM-GERDAT) and an improvement in the scientific job policy.

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FRANCE

POLICIES, METHODS FOR PETROLEUM RECOVERY REVIEWED

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[Unsigned article: "The Assisted Recovery of Petroleum"]

[Text] In order to balance the energy supply and demand, by the end of this century hydrocarbons (oil and gas) will still provide nearly 50 percent of the world's energy requirements: oil consumption will go from  $3 \times 10^9$  tons to about  $4.5 \times 10^9$  tons per year.

Under the present industrial conditions, recoverable reserves are about 300 billion tons. These figures indicate that no immediate shortage would exist if the extraction of hydrocarbons were total: this is far from being so, and some 70 percent of the oil remains in the ground.

In the great majority of cases, the exploitation of deposits begins with a so-called primary recovery phase, which makes use of the actual energy contained in the reservoir (expansion of solids and fluids, expansion of an aquifer or of a gas-cap).

This phase allows only a limited recovery (15 to 20 percent on the average) of available reserves, especially in the case of heavy oils. This figure can be raised through the use of assisted recovery methods, all of which consist of injecting a suitable product to extract the oil from the rock toward production wells, and/or to modify the characteristics of the oil (viscosity, etc.) so as to facilitate its removal. In keeping with American terminology, we have:

First generation assisted recovery methods, known as secondary methods because they are applied after the primary natural expansion phase; they involve the injection of water and of dry gases.

These methods lead to the recovery of an additional 10 to 15 percent oil;

Sophisticated methods under development, known as tertiary methods because they are being used in the United States on deposits that are exhausted after the injection of water or dry gases. Among these methods are:

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Injection of aqueous solutions of surface-active polymers;

Injection of hydrocarbon gases miscible with oil, CO<sub>2</sub>, combustion gas;

In situ combustion (through air injection) and steam injection, these methods being appropriate only for heavy oil deposits.

The diverse characteristics of various deposits involves the availability of many methods, making it possible to select the most suitable solution.

Water or gas injection (secondary recovery) has already entered an industrial utilization phase, since more than 7000 installations are operating in the United States, and 80 percent of the Russian deposits are producing with water injection equipment. Moreover, the majority of ocean deposits are now equipped with such devices from the beginning of the production phase.

The use of tertiary recovery methods is being developed rapidly, notably in North America, as a result of improved knowledge of techniques and increased crude oil prices. The most significant industrial developments are currently being pursued in the United States, which is thus attempting to sustain its oil production rate. However, many pilot installations are appearing throughout the world, demonstrating the concern of producing nations to preserve their reserves, and of operators to exploit their technologies.

In terms of cost, the traditional secondary recovery methods are relatively inexpensive (injection of water and eventually of gas), generally falling between \$1 and \$5/bbl, with the higher amounts representing marine installations.

Tertiary recovery methods result in a crude whose production costs are high, but which often fall within acceptable economic limits.

Thermal methods, the only ones usable for heavy crudes, result in costs of the order of \$5 to \$15/bbl. In the case of injections of water that contains chemical additives, or of miscible gases, one can expect costs of \$10 to \$15/bbl. Recent studies show that the majority of the reserves technically accessible through tertiary recovery methods can be reached at a technical cost of less than or equal to \$25/bbl.

An early intervention of these methods in exploitation makes the process more economical.

As technologic progress becomes more widespread throughout the world, most deposits will become potential candidates for assisted recovery. In addition, heavy oil deposits which are currently not exploitable, will be usable through thermal methods. The policies of producing countries, and especially of those with poor reserves, or of countries with oil shortages, will strongly contribute to the application of assisted recoveries.

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In France, the systematic installation of assisted recovery at French deposits would make it possible to produce several million additional tons, but more importantly, it would enable the French industry to master these processes.

In research, several approaches are currently being followed to improve tertiary recovery.

Since 1973, the General Delegation for Scientific and Technical Research (DGRST) has instituted a Concerted Action (CA) for the Assisted Recovery of Petroleum (RAP) in close association with the French Petroleum Institute (IFP) and the French Petroleum Companies (CPF).

The goals of the CA have been:

To encourage university laboratories to become involved in this very important field of research;

To help exploitation and deposits petroleum specialists in fundamental areas, by providing basic scientific knowledge for a better understanding of phenomena, ultimately leading to higher efficiency in recovery.

Two major essential options have so far been the object of the most important studies:

- I. Recovery by injection of water and additives;
- II. Study of the factors in liquid-steam equilibrium.

Water is the most often used motive fluid, but its efficiency is limited by capillary action, wettability of the rock, and interface tensions. For these various reasons, it is preferable in RAP to introduce additives in the injected water, so as to modify its characteristics and increase the volume that is being swept.

In order to improve the efficiency of the water sweeping, one can use micellar solutions which make it possible to solubilize a portion of the oil so that it will come in contact with a larger number of pores. The most widely used approach consists of injecting a limited volume of surfactants (generally, sulfonates derived from petroleum), which are pushed into the deposit by water whose motion is stabilized with water-soluble polymers (polyacryl- amides or polysaccharides).

It thus becomes possible to synthesize inexpensive additives that can solubilize oil, or at least sufficiently reduce the water-oil interface tension (surfactants, microemulsions) and sufficiently increase the viscosity of the injection water (polymers).

The prepared additives must meet a certain number of constraints which take into consideration the characteristics of the petroleum deposits (temperature, ion, and mechanical stability, etc.)

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However, almost nothing is known about the behavior of polymers in porous media, and despite the work that has already been performed, it is impossible to judiciously select a product appropriate for a given deposit. Similarly, the action of surfactants in RAP is very poorly understood, and their means of utilization uncertain.

Other fluids are also usable, and that is why it is possible to inject gases (CO<sub>2</sub> or miscible gases) or steam. A knowledge of liquid-steam equilibrium factors comes into play in this case, as in fact in the case of other stages of petroleum recovery.

The great depths at which exploration is conducted cause the liquids in deposits to exist under conditions of composition and pressure for which the available experimental data and methods of calculation are inadequate.

These research topics also include the study of interactions within the rock and analyses of the media under study.

The nature of this AC is undoubtedly very special, the field of RAP being an entirely new one for most university laboratories. Nevertheless, the response of basic researchers to the requests of the petroleum sector has been significant: since 1974 and until the end of 1977, a total of 161 projects have been proposed to the committee.

Contracts have been primarily awarded in the first of the suggested domains, numerous laboratories having been attracted by research in the field of micellar solutions and microemulsions.

The fundamental merit of the AC is to have renewed interest in a field of study which until then had been limited to a few physical chemistry teams. Through participation at an EUCHEM meeting (26-30 April 1976) on the chemistry of interfaces, followed by a summer school in Aussois (12-24 September 1977) on colloids and interfaces, this initiative was sustained by a training activity whose benefits will be felt in a renewed teaching of this discipline.

In addition, it was possible to initiate a collaboration with the major American research group engaged in this type of work. Two French researchers completed a working visit at the Austin laboratory, and others will be able to work in French laboratories as well.

Foreign specialists have on several occasions described to the extended committee the results of their work, as well as their ideas on the direction in which this research should be pursued.

One of the most significant results of the AC RAP is certainly to have raised the awareness of university researchers about the need to undertake basic research in this sector which is so important to our economy, and to have given new impetus to colloidal chemistry and to the thermodynamics of

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microemulsions (a GRECO is currently being established within the CNRS (National Center for Scientific Research)). In addition, the constant collaboration between researchers in public organizations and engineers of the petroleum companies or of the IFP, has made it possible to retain a sense of concrete realities, and to better define in fundamental terms, the practical problems faced by professionals.

In the new request for proposals sent out in May 1979, the committee has listed three major topics:

Recovery by injection of water and additives;  
Recovery by thermal methods or by injection of CO<sub>2</sub> or solvents;  
Study of the liquid-steam equilibrium factors.

In what follows, we present these research expectations as they have been introduced by the request for proposals, which given its scientific and technical interest, we reproduce in its entirety.

Topic I. Recovery by Injection of Water and Additives

Purpose of Research into Recovery by Injection of Water and Additives

At present, the exploitation of a petroleum deposit almost always proceeds as follows: after the reserves are estimated by means of geophysical measurements, and after soundings of the producing structure connect the petroleum level with the surface, the pressure existing at the head of these wells is progressively reduced to values close to atmospheric pressure. The oil is then extracted through simple elastic decompression. In general, the oil in the deposit contains dissolved gases which are partially released when the pressure is reduced. This release causes the extraction of a complementary volume of oil. It is estimated that an average of 10 to 15 percent of the oil initially present is recovered during this depletion phase.

Frequently, water is injected into the deposit during a second stage, through bore-holes drilled specially for this purpose. Its function is to sweep the porous medium containing the hydrocarbons, and to push them toward production wells. Depending on circumstances, this operation is sustained for 5 to 15 years, and is stopped when the water content of the produced mixture makes it uneconomical. At that point, the recovered oil represents 30 to 40 percent of the initial volume.

It might seem surprising that the recovery is so poor, but there are several reasons for this. First, if the water movement is examined macroscopically, one observes that its higher mobility with respect to the oil is a source of instabilities: the injected water tends to follow the path of least resistance and goes directly to the production wells. As a result, only a portion of the zone is effectively swept (50 percent as a figure of merit).

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This failure of the sweeping action is of course enhanced by the natural heterogeneity of sedimentary deposits, and by the contrast in the density of the fluids, which does not encourage the drainage of the higher portions of the deposit.

Secondly, if one examines the portion that is effectively swept, one observes that even at the final stage, the water succeeds in displacing only about one half of the oil which it contains. For one must not overlook the fact that the oil is stored within the pores of sedimentary media, pores whose dimensions generally lie between 0.1 and 100 microns. Capillarity effects are predominant, and since the medium is preferentially wettable by water, the oil is rapidly trapped in the form of discontinuous microglobules which given the available energy, can no longer cross the capillary thresholds. Moreover, the oil is bound more or less rigidly to the surface of the rock, generally by physisorption but without excluding chemical and/or dipole-dipole bonds.

Various solutions have been studied and have led to several full-scale tests aimed at improving the efficiency of water sweeping, through the use of additives.

In particular, a natural inclination is to modify the characteristics of the water in order to reduce its mobility, and thus increase the swept volume. The method with which experiments are currently being conducted, consists of solubilizing polymers (polyacrylamides or polysaccharides) into the injection water; in some cases, this method has led to very encouraging results. However, almost nothing is known about the behavior of polymers in porous media, and despite the work that has been conducted, it is impossible to judiciously select a product appropriate for a given deposit. For the time being, these products are chosen by trial and error among commercially available ones, the latter being synthesized without precise orientations.

In addition, in order to recover more oil from the zones swept by water, we considered the use of, among other things, micellar solutions which would make it possible to solubilize part of the oil and to make contact with a larger number of pores. The most widely adopted approach at present consists of injecting a limited volume of sulfonates derived from petroleum, and of pushing them into deposits by means of water whose movement has been stabilized with polymers. The action of surfactants in RAP is very poorly known, and their conditions of use uncertain. Nevertheless, this approach seems promising; laboratory tests conducted here and there show that all economic considerations aside, it is possible to achieve recovery rates close to 100 percent.

The committee expects from researchers a fundamental and multidisciplinary effort at understanding the action of these additives in porous media, in the presence of hydrocarbons and of water solutions with high ionic strength.

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Research on Procedures

The solution of the problems raised (improved sweeping and microscopic displacement of the oil) requires a knowledge of the nature and properties of the fluids and solid surfaces under consideration.

In order to improve our understanding of the phenomena and mechanisms involved during the injection of micellar and polymer solutions, the following points need to be studied:

Research on Surfactants

This concerns the study of micellar solutions, either in the form of aqueous solutions of surfactants (concentrated or not), or in the form of microemulsions (microscopically monophasic water-oil-surfactant solution systems).

Characterization and Properties of Micellar Systems

An improved macroscopic and molecular description will be sought for the various domains of the phase diagrams.

Thermodynamic properties: study of phase diagrams for water-alcohol-surfactant-oil mixtures with dissolved salts. Demonstration of gels and precipitates.

Interface properties: research and understanding of the conditions necessary for obtaining low interface tensions (of the order of millidyne/cm), and of the conditions for strong solubilization of oil and water. Study of the interface structure (low tension) and of the intermediate phase of triphase systems under optimum conditions. Interface effect of alcohols. Thermodynamic aspects.

Rheologic properties: relation with the structure of micellar phases. Characterization of the parameters which significantly influence the viscosity of systems. Prevention of gels, notably in water-rich compositions.

Stability: long-term modification of the structure of micellar phases, formation of liquid crystals, equilibrium kinetics of polyphase systems (role of alcohols).

Compatibility: interactions of surfactants with polymers, ionic environments, alcohols, and solid surfaces (also see below: Behavior of Micellar Solutions in Porous Media, and Interaction of Polymers and Surfactants).

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behavior of Micellar Solutions in Porous Media

a) Adsorption (liquid-solid interaction) and generally, all phenomena responsible for the retention of additives (surfactants, alcohols) by porous media (also see below).

Correlation between retention and type of phase diagram, concentration of additives, structure of micellar solutions.

b) Dilution (liquid-liquid interaction).

Maintenance of low interface tensions, research into surfactants efficient at low concentrations.

Compatibility with aqueous polymer solutions. Prevention of gels and precipitates.

The following parameters will be taken into consideration throughout the proposed studies:

Nature, structure, and eventually polydispersity (polymolecularity) of constituents: water (salinity, pH), hydrocarbons, surfactants, supplementary additives (notably alcohols).

Surfactant products will be sought which are best adapted to various difficult conditions:

Temperature;

Concentration of constituents: water/hydrocarbon ratio, concentration of amphiphile components, presence of divalent cations, high salinity;

Nature and surface conditions of the rock, clayey medium, and carbonates.

Study of Oil Release Mechanisms

Among the usually accepted oil release mechanisms, studies will seek to specify the respective roles played by miscibility, material transfers (including the kinetic aspects of these transfers), and reductions in interface tension.

Also examined will be any other mechanisms, such as those which involve the rheology of interfaces or modifications of contact angles.

Analyses

In order to aid in the interpretation of liquid-liquid (phase behavior, material transfer) and liquid-solid (adsorption) interactions, improvements will be sought in the means of analysis of ionic and non-ionic surfactants under various conditions:

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Dosage in aqueous and organic phases;  
Evaluation of polydispersivity (polymolecularity);  
Problems raised by the presence of other additives (polymers, alcohols,  
other surfactants);  
Dosage on the rock;  
Precise dosage in concentrated systems.

This analysis effort will also have to be directed toward the constituents of crude oils, and particularly toward polar substances and heavy products (see Topic II).

Research on Polymers

Adsorption on natural rocks: chemical and physical factors of adsorption.

Formation and elimination of gels or microgels, which are the source of serious choking:

Inherent reticulation of polymers: modification of synthesis conditions;  
Reticulation due to interaction with various multivalent ions such as  $\text{Fe}^{++}$ ,  $\text{Fe}^{+++}$ ,  $\text{Al}^{+++}$ , and  $\text{B}^{+++}$ : use of sequestering agents compatible with polymers.

Time stability:

Conjugated action of oxygen, oxidizers, and temperature: demonstration and remedies (anti-oxidants);  
Bacteria: identification and use of bactericides;  
Compatibility of additives used with polymers, and the environment: absence of gels, insolubility in oil, poor adsorbance.

Research on polymers usable under severe conditions (high salinity and temperature, extreme pH) and meeting criteria of solubility, viscosity, filterability, and limited adsorption.

Interaction of polymers and surfactants: conditions of formation of gels or precipitates, phase separation, competitive adsorption on the rock..

Solid-Liquid Interactions

The studies will use reservoir rock or solids which simulate it:

Silica: quartzitic sand and sandstone;  
Clay: clayey sand and sandstone;  
Carbonate: chalk, dolomite, calcarous cement sandtone.

Study of Phenomena

Thermodynamic equilibrium of rock-saline solutions.

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Electrochemical study of the solid-liquid interface.

Study of the adsorption of surfactants in micellar media, and of polymers.  
Nature of adsorbant interactions. Adsorption and desorption kinetics.

Determination of conditions for minimal retention (notably the influence of the structure of chemical additives).

Research on adsorption palliatives: choice of additives, sacrificed products, pre-treatment of the rock.

Solid-water-organic material (crude oil) interactions: wettability, origin of retention in porous media. Study of release mechanisms other than miscibility, material transfer, and reduction of interface tension among liquids.

Parameters for Study

Those mentioned above.

Investigation Methods

All projects concerning techniques for studying the intimate nature of adsorbed phases on solids (NMR, IR, interferometry) will be investigated with attention, as long as they are effectively adapted to solids with specific surfaces lower than  $20 \text{ m}^2/\text{g}$ .

Research on New Additives

The aim is to find additives capable of causing, simultaneously or separately:

A sufficient increase in the viscosity of the injection water (polymers);  
The solubilization of a portion of the oil, or at least a sufficient reduction in the interface tension of water-oil mixtures (surfactants or microemulsions).

These additives must be able to support the constraints of deposits. In the most severe cases they must be:

Stable with temperature (up to  $120^\circ\text{C}$ );  
Stable in the presence of ions contained in the injection water and in the deposit (3-200 g/l NaCl and 30 g/l  $\text{CaCl}_2$ , for instance);  
Chemically stable (pH between 3 and 9);  
Poorly adsorbable on the surface of pores;  
Mechanically stable (shear rates up to  $100 \text{ s}^{-1}$ );  
Non-degradable by bacteria contained in the injection water.

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Topic II. Recovery by Thermal Methods and by Injection of CO<sub>2</sub> or Solvents

Statement of Problem

Thermal methods are well adapted to the exploitation of heavy oil deposits. Oil recovery is helped by a strong reduction in the residual oil content, as well as in the oil/water viscosity contrast when the temperature increases.

Two classes of thermal methods are known: injection of hot fluids, steam in particular, and in situ combustion.

At present, water injection is the most widely used method of improved recovery. It is responsible for the production of 9 million cubic meters of oil in California, and of an essentially identical amount in Venezuela. Water injection can be applied by two methods: cyclic injection which consists of the injection of a given volume of steam, followed by the return to production of the stimulated well, and by a displacement from well to well.

In situ combustion is a technique in which a portion of the oil in the reservoir is burned with air oxygen injected through various wells. This develops a combustion front whose temperature is generally between 400 and 600 °C, and which moves from the injection wells to the production well (co-current combustion). The heating of the environment facilitates the production of the non-burned oil fraction. The performance of co-current combustion is significantly improved by combining water injection with air injection. Until now, in situ combustion has had a less spectacular development than steam injection, in large part because the procedure is more difficult to implement.

On the other hand, carbon dioxide injection is a process well adapted to the exploitation of certain deposits of medium-weight or heavy oils located at depths beyond the limit usually accepted for thermal methods (1000-1500 m). For medium-weight oils, it is possible to attain oil/CO<sub>2</sub> miscibility, leading to excellent displacement coefficients, whereas for heavy oils, the recovery gain results from a very significant reduction in the viscosity of the oil, following the dissolution of the CO<sub>2</sub> and the swelling of the oil.

Avenues of Research

Interactions Between Fluids and Fluids/Matrix

Compatibility of Crude Oil/Injected Product

The injection of carbon dioxide or of a liquid hydrocarbon solvent (sometimes used for some heavy oil deposits) assumes a compatibility between the injected fluid and the crude oil. In particular, it would be desirable to know the precipitation criteria of various heavy products likely to choke

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to formation (asphaltenes). In general, it would be useful to have a better understanding of the nature of the heavy products and of their thermal behavior.

Fluids/Matrix Interaction

The selective adsorption phenomena of certain constituents of the oil in porous media are very important for determining the residual oil saturation during displacement with a hot fluid, or the amount of available fuel for co-current combustion.

Injection of Hot Fluids

Some work has shown the influence of temperature on the absolute permeability of rocks with constant effective constraints. However, the results obtained are still qualitative and fragmentary.

The displacement of certain constituents of the oil by selective vaporization (stripping), is an important mechanism when steam is injected in oils that contain sizable amounts of light fractions. This effect should be evaluated experimentally and theoretically.

Research on surfactants to improve the efficiency of displacement by steam.

The combined injection of steam and additives could lead to an improved performance of displacement by steam. However, these additives must be stable in the presence of fluids and of the deposit rock at the temperature of the steam, that is at 200-300 °C, taking into consideration the injection pressure. These very severe conditions are not met by most commercial products.

These additives should fulfill one of the following functions:

Agents to reduce the oil/water interface tension, so as to increase the displacement efficiency;

Basic constituents of a foam which blocks the steam flow into the most permeable zones, thus leading to improved sweeping effectiveness.

Injection of Carbon Dioxide or Solvents

This method requires a knowledge of various thermodynamic data developed as part of topic III.

Topic III. Study of Liquid/Steam Equilibrium Factors

Economic and Industrial Motivations

Introduction

A knowledge of the liquid/steam equilibrium factors is required at various stages of petroleum recovery: primary, secondary (gas injection: CO<sub>2</sub> or

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miscible gases, steam), separation, and collection and transportation network.

This knowledge rests first of all on direct experimental information (essentially a volumetric study of deposit liquids under conditions simulating their known or assumed evolution), or indirect information (laboratory determination of equilibria for typical mixtures, selected on the basis of the composition of the oils and gases under consideration), and on the possibility of representing these equilibria to the extent to which a reliable method of calculation is available.

Moreover, given the large depths to which exploration and exploitation are currently being conducted, the deposit fluids exist under conditions of composition (high contents of light components) and pressure (exceptionally high) which are likely to create liquid/steam separation phenomena that could fall in critical domains. These same equilibria also exist for oil/gas (or gasoline/gas) separations in production and treatment installations, notably in the case of sea deposits.

That is why the research program described below concerns primarily the ELV of hydrocarbon and gas mixtures which are generally found in natural fluids ( $N_2$ ,  $H_2S$ ,  $CO_2$ ), in the critical domain ( $P > 0.8P_c$ ) for which currently available methods are inadequate, the aim being the perfection of a thermodynamic model leading to reliable results during calculations required for studies of deposits and production.

The vast domain of pressures and temperatures within which the need exists to know the properties of condensate oils and gases, and the fact that the compositions of diphasic mixtures are constantly changing during their movement in deposits or exploitation installations, are obvious examples of the need to be able to calculate these properties, thereby avoiding the recourse to excessive laboratory efforts.

To conclude, there exists the possibility of extending an appropriate thermodynamic model to triphase equilibria in the presence of a solid phase, the latter capable of being either gas hydrates, paraffins, or asphaltenes, as well as to equilibria in the presence of an aqueous phase containing electrolytes and capable of dissolving various gaseous constituents, notably the acid gases  $CO_2$  and  $H_2S$ .

#### Deposit Problems

In general, liquid phases and gaseous phases do not circulate at the same average speed in deposits, so that the actual composition of a diphasic mixture present at a given location (a small volume of rock centered around a given point) never stops changing. Yet it is this overall composition that determines the composition of the two phases which will move, and to the extent to which viscosities, surface properties, and volumetric masses come into play, the very conditions of this movement. It should be pointed

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out that the ELV in critical regions cause phases whose relative volumes and compositions change very rapidly with pressure (therefore particularly in the proximity of production wells).

That is why a representation of the behavior in deposits requires a compositional model. It should however be noted that a crucial problem exists in identifying the heavy residue (generally  $C_7+$ ) by magnitudes which will enter in the model when it is used to study the properties of the overall mixture.

A compositional model established in this way must be considered primarily as a phenomenological model, that is, one which can be used in the laboratory to specify the influence of the various parameters.

In economical terms, its use could lead, among other things, to a reduction of the time needed to place in production reservoirs containing a fluid in the neighborhood of critical conditions, as a result of a better definition of the method of exploitation of such deposits, an estimate which can currently be made only through lengthy laboratory experiments.

In addition, the most accurate possible estimate of the evolution of gasoline resources with pressure in gas deposits is of increased importance, because this pressure is created by the hydrocarbons whose economic exploitation is the most interesting one among all those that exist in the gas.

#### Problems of Assisted Recovery

The economic importance of assisted recovery operations is considerable, since it makes it possible to increase the quantities of produced hydrocarbons; in these operations, the field of application of thermodynamic studies can cover three types of important processes.

a) Injection of gases that are partially miscible with existing oils: the total composition of the two phases in the zone of miscibility is in the critical region, and the efficiency of the isothermal movement is partially controlled by the material transfer process between the existing and injected fluids; the process must be therefore be optimized on the basis of a model that describes the diphase equilibria of the multicomponent mixtures, and that best reflects the real phenomena.

Another notable application is the calculation of the recovery due to recycling in the case of condensate gases.

b) Given the growing importance of thermal methods in assisted recovery (injection of hot water or steam, and dry or wet combustion), which cause local temperature variations in deposits, and which thus generate vaporizations and condensations, it becomes necessary to determine the simultaneous influence of temperature and water on oil/gas equilibria.

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c) As part of the injection of anhydrous carbon dioxide (in gas phase or dissolved in water), major mechanisms are brought into play: reduced viscosity, increase of mass volume, and movements which under certain conditions can be miscible; these mechanisms can be partially described and predicted by a compositional model.

Surface Problems

The design of exploitation and calculations for surface installations require a knowledge of the diphasic behavior of oils and condensate gases through a broad range of pressures and temperatures.

The exploitation of sea deposits also demands a very accurate knowledge of separation conditions, because the general problem of sizing surface installations is particularly crucial due to the space limitations of platforms. Moreover, the trend toward drilling through very deep waters will certainly raise new problems, such as the choice of performing immersed separations, which will require accurate definitions of optimum pressures and temperatures for these operations.

Scientific Problems

In scientific terms, all these very diverse applications raise the same problem: the search for accurate methods to forecast the thermodynamic properties of complex mixtures of hydrocarbons (from  $C_1$  to heavy fractions), sometimes containing  $H_2O$ ,  $H_2S$ ,  $CO_2$ , and  $N_2$ , over a broad range of pressures and temperatures, with particular stress being placed on the critical zone ( $P > 0.8$ ).

At the present time, the most urgent needs facing deposits and production engineers are the following:

- a) Development of a reliable calculation model for the volumetric properties of condensed phases (oil or condensate), the shortcoming of current methods being above all, the absence of experimental data on the volume masses ( $P$ ,  $T$ ) of the hydrocarbons which compose the residue  $C_7+$ ;
- b) One predominant avenue of research therefore, is to demonstrate the influence of the volatility and of the chemical nature of the heavy components of the  $C_7+$  complex, and to characterize them by physicochemical parameters usable in thermodynamic models applied to petroleum fluids;
- c) The experimental data available in the literature on liquid/steam equilibria, is insufficient to calculate the binary interaction parameters of models representing equilibria, notably in the case of mixtures containing heavy hydrocarbons. The published data should therefore be completed so as to cover the domains of practical interest:

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Pressures of up to 1000 bars for temperatures in the 0-160 °C range, corresponding to operating conditions in deposits, in the treatment of oils, in production areas, and in gas transportation;  
Pressures of up to 150 bars for temperatures in the -40 to 0 °C range, corresponding to operating conditions in the treatment of natural gas in production areas.

The experimental study will be carried out on mixtures selected to provide solutions for the various problems listed here, and in particular to obtain parameters characterizing heavy hydrocarbon cuts, and the extended applicability of models to petroleum fluids. Measurements are equally necessary on synthetic multicomponent mixtures, in order to test methods for predicting equilibria.

All these measurements will provide an experimental basis for complementary theoretical studies;

d) The most difficult theoretical problem is the calculation of equilibria, that is, the calculation of relative compositions and quantities in phases at given pressures and temperatures, for mixtures with given overall compositions. Thermodynamics allows the calculation of ELV from the equality of fugacities in the vapor and liquid phase of each constituent. The problem then becomes to know the fugacities as a function of the variables pressure, temperature, and composition of the phase.

A particularly interesting case is that of mixtures containing heavy cuts which should be characterized by families. The purpose of theoretical research is to provide models whose parameters are correlated in a simple way with the molecular properties of pure bodies, size and shape of molecules.

e) An essential aspect of these studies is the knowledge they will provide about the critical values of mixtures, making it possible to properly locate operating conditions (P, T) with respect to the critical domain. Eventually, the measurement and correlation of volumetric and/or equilibrium properties in this domain should permit the extension of forecasting techniques into the critical region.

Proposed Avenues of Research

Measurement of liquid/steam volumetric and equilibrium properties, and of critical values for hydrocarbon mixtures typical of those encountered in RAP.

Representation of thermodynamic properties (density and equilibrium among phases of multicomponent systems) by means of state equations, excess functions, or partition functions, incorporating the progress made in molecular theories.

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An important problem is the characterization of heavy molecular weight hydrocarbons present in crude petroleum, by regrouping them into families.

The aim of the experimental work will be to obtain parameters necessary both for practical calculations and for the study of theoretical models.

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